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The Soil Reacting Forces from Field Studies with a Rotating Rod

by

Richard Price Atkins

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled The Soil Reacting Forces from Field Studies with a Rotating Rod

.....

submitted by Richard Price Atkins

in partial fulfilment of the requirements for the degree of Master of Science (Ag. Eng.)

ABSTRACT

The objective of this field study was to determine the soil reacting forces of a rotating rod. The rod weeder being a secondary tillage tool is mainly used under loose, cohesionless soil conditions. The data were collected using a multicomponent sensor and a data acquisition system to measure the forces on the rod. A split plot factorial design was used and the factors tested were soil sites, depth of operation, rod shape, rod speed and ground speed. The rod shape, rod speed and ground speed all tested highly significant for draft and vertical reaction. The round rod has greater draft than does the square rod because more soil passes under the round rod causing more compaction and using more energy. The amount of soil that goes over and under the rod is the plane of separation and is determined by the peripheral velocity of the rod, the soil-metal and the soil-soil friction forces. The shaft power per meter of rod ranges from 27 w/m to 52 w/m and is negligible when compared to the drawbar power which varied from 1680 w/m to 2300 w/m.

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1. INTRODUCTION

The development of rod weeders, beginning in 1910, has been a trial and error procedure. Most of the development of the rod weeder has been the result of innovations by farmers. Eventually farm machinery companies refined these designs into the present implement. The objective of this experimental study was to determine the soil reacting forces of a rotating rod under field conditions because little was known of the soil dynamics with a rod weeder. From the results of the study a better or more economical tillage tool possibly could be developed. With the current need to conserve energy, low draft tillage tools are important. In Alberta in 1975 there were seven million acres under summerfallow and 98 million dollars worth of fuels and lubricants were consumed in farm operation (1). If farmers could increase their field efficiency by just 10% by using a low draft tillage tool, the savings in fuel would be substantial.

2. LITERATURE REVIEW

2.1. Tillage Objectives

Since man has been growing his own food, he has practiced some form of cultivation or tillage and has formulated many theories on the objectives of tillage. In Greek and Roman times farmers were fully convinced that soil fertility would be improved if the soil was periodically loosened and mixed. This classical concept was refined by Jethro Tull in the 18th century, who suggested that plant roots consumed and fed on soil particles. Hence the more refined the size of the soil particles due to cultivation, the more the plant roots could absorb. By the 20th century, objectives and effects of tillage were more fully understood due to the advancements in all technical fields of agriculture (2). The following is a list of present day tillage objectives (18):

(i) Development of a soil structure or soil consistency in the upper tillage zone with a desirable degree of aeration and density.

(ii) Eradication or management of weeds, volunteer crops or plant residues.

(iii) Establishment of soil boundaries and surface configurations for the purpose of seedbed preparations or soil conservation (e.g. contour furrows to control erosion).

(iv) Incorporation or mixing of foreign materials (e.g. fertilizer, herbicides) into the soil.

(v) Segregation of soil particles or plant residues.

Therefore the aim of tillage is the manipulation of a soil by mechanical means, from a known state to a desired state for economic

crop production (7, 12, 18). Unfortunately most tillage is not properly coordinated with optimum soil working conditions (e.g. moisture content); consequently there is a need for additional tillage operations to achieve the desired state (2).

2.2. Types of Tillage Practices

Tillage is initially classified into primary and secondary operations. Primary tillage is the initial soil working operation which is intended to reduce soil strength, cover plant residues and rearrange the aggregates. Secondary tillage is intended to create refined aggregation following the primary tillage as well as weed control (18). For this reason the rod weeder is classified as a secondary tillage tool.

Under semi-arid or dryland farming conditions, special tillage practices have been developed. There are two major concerns under semi-arid conditions: erosion control and moisture conservation. The practice of summerfallowing, which is leaving land out of production for one cropping season to allow a conservation of nutrients and moisture in the fallow land, is an effective cultural practice in dryland farming. As a result of summerfallowing, special tillage problems had to be overcome. The tillage practices that have developed to overcome tillage problems with summerfallow are minimum tillage, zero tillage and stubble mulching.

As a result of specialized tillage practices utilized under semi-arid conditions, tillage objectives have become more specific in their purpose:

(i) The conservation of moisture becomes the ultimate aim of tillage practices (17, 18). With appropriate tillage

practices infiltration, evaporation and runoff can be modified. A rough, well aggregated surface increases infiltration, thus decreasing runoff. By maintaining a compacted moist layer of soil at the bottom of the tillage zone and a loose, dry layer at the top of the tillage zone, evaporation can be minimized. The dry loose zone forms a barrier to upward water movement.

(ii) Weed and plant growth control is essential in conserving vital nutrients and moisture (17, 18). By controlling and destroying weeds during the summerfallowing operation, the following crop requires less weed control by herbicides.

(iii) By maintaining a rough surface, good aggregation and soil structure, soil erosion is reduced, soil crusting is minimized and the thermal conductivity is reduced such that the soil surface will act as a thermal buffer zone (7, 17).

As a result of using primary tillage implements for secondary tillage operations under dryland conditions in the 1930's, excessive erosion took place. By leaving a trash cover or stubble mulch at the surface rather than incorporating the straw, erosion can be reduced to as much as one-fifth (2). The added benefits of stubble mulching are: increased infiltration, reduced erosion, and reduced evaporation. For stubble mulching practices, new tillage tools were developed that would minimize soil inversion. Secondary tillage tools such as rod weeders and wide sweep cultivators only invert 5% to 15% of the trash per operation (9).

The rod weeder developed into a tillage tool capable of large capacities, of achieving a desirable soil state, of effectively

controlling weeds and of handling trash to maintain a stubble mulch.

2.3. Soil Dynamics in Tillage

Soil dynamics is defined as a phase of soil science and mechanics concerned with soils in motion. More specifically, soil dynamics is the relationship between forces applied to the soil and the resulting soil reaction (12). Cultivated soil has a constantly changing physical state which makes a quantative analysis difficult, hence the ultimate design of tillage tools is done by observation under field conditions. The following sections describe the major aspects of soil dynamics.

2.3.1. Failure Theory

For a tillage tool to effectively manipulate the soil, the soil must deform, fail or move in some way (12). There are many forms in which failure takes place. First of all, the soil may deform elastically or plastically or both in the vicinity of the tillage tool as the tool moves through the soil (16).

Elastic deformation occurs when the displaced or stressed soil returns to its original state without loss or gain of volume. Plastic deformation occurs when the displaced or stressed soil has deformed in some way such that the soil strain is permanent (i.e. compaction, etc.). Plastic flow of soil around a tillage tool is a common occurence in loose soils especially under secondary tillage operations (6, 12, 30). To date, elasticity and plasticity theories cannot be directly applied to soil dynamics but still form the basis for analysis.

When dense soils fail with tillage tools, they fail by compression,

tension, and shear (33). The common types of failure in secondary tillage operations are compression and shear (20). A common occurence in cohesionless soils is soil flow which is essentially soil displacement by shear. All types of failure are present in varying degrees and the extent of each type of failure depends on the soil strength.

When a loose or dense soil fails as the result of compressive stresses, deformation usually occurs resulting in a loss of volume (i.e. compaction). Compressive stresses are quite apparent when using blunt or dull tillage tools (4, 11, 12). A great deal more energy is required to fail a compacted soil.

Shear stresses exist in a complex manner under typical shear failures. Figure 1 shows the two extreme types of shear failure planes (12, 28). Most shear failure planes lie somewhere between the two extremes. The shear failure path, whether starting upward from the tool tip or sweeping down and up from the tool tip, depends on factors such as soil conditions, tool speed, lift height and depth (11). The shear failure path is the result of the rotation of the principal stresses on finite elements of soil. For shear failure to take place, three dimensional shear stresses and normal stresses develop within the soil mass. Again soil strength properties determine how the soil reacts to shear and normal stresses. There is a tendency for a loose soil with very little soil strength to decrease or compact in volume during shear (24). On the other hand, if a dense cemented soil is to fail in shear, the high degree of interlocking particles (e.g. soil strength) must be overcome by fracturing of the particle thus increasing in volume (20).

The complexity of soil failure, as a result of mechanical manipu-

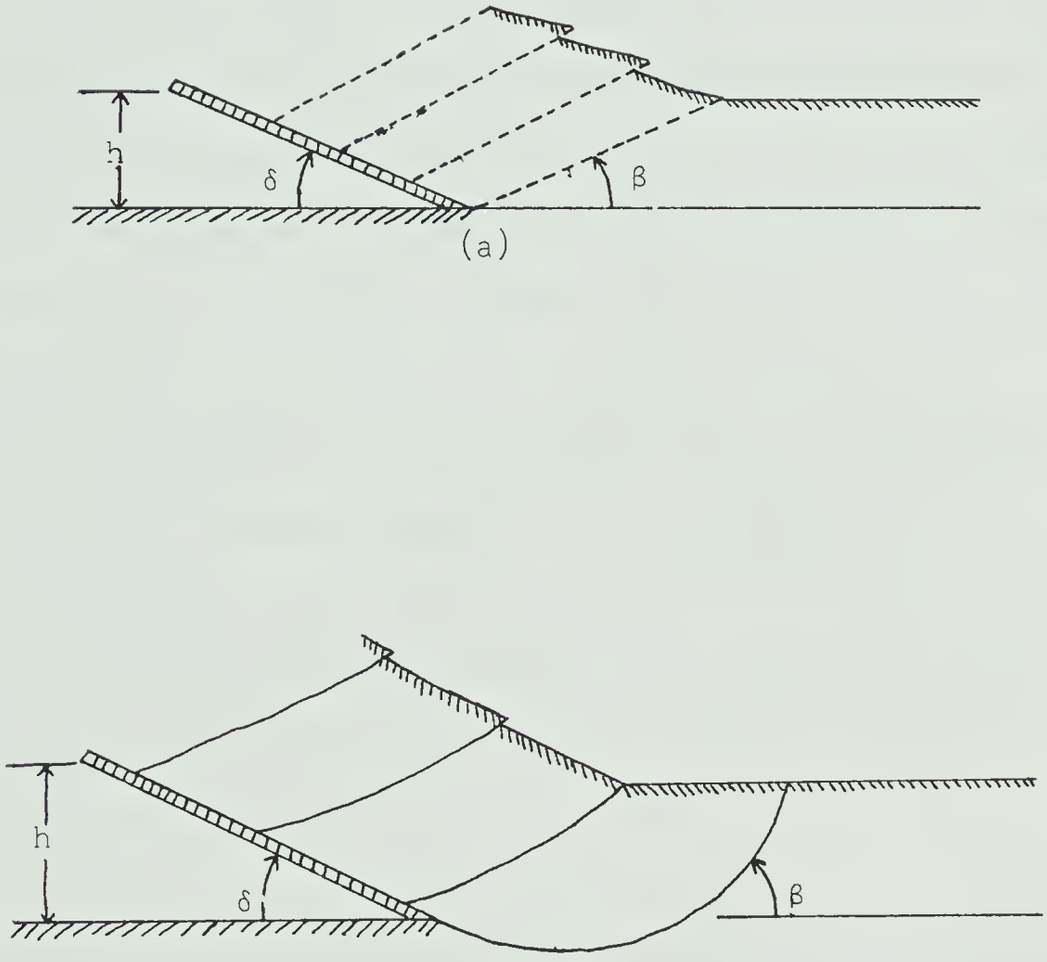


Figure 1: Types of shear failure

lation, makes a quantitative analysis extremely difficult. Therefore most studies concentrate on the soil reacting force rather than shear, tensile, compressive, frictional and cutting component forces.

2.3.2. Frictional Forces

Any time a medium has an interface with another object, and a force is applied, frictional forces develop at the interface as well as in the medium. Besides induced frictional forces there exists at all times internal friction among the interlocking particles of the soil mass. The law of motion, that states for every action there is an equal and opposite reaction, is the basis for determining soil reaction forces. The force applied to the tillage tool must be able to overcome the frictional forces related to the soil failure and the cohesive strength of the soil particles, as well as the sliding frictional forces of the soil passing over the tillage tool.

There are two types of friction related to tillage tool operation. First is soil to soil friction which is the cohesive and adhesive bonding of soil aggregates and basically follows Coulomb's law of friction (18):

$$\mu = \frac{F}{N} = \tan \delta$$

where μ is the coefficient of sliding friction, F is the frictional force tangent to the surface, N is the normal force perpendicular to the surface and δ is the angle whose tangent is μ. From Coulomb's law of friction developed an equation to incorporate cohesion and to calculate the shear stress (18):

$$\tau = C + \sigma \tan \phi$$

where τ is the shear stress, C is cohesion, σ is the normal stress and ϕ is the angle of internal friction. For cohesionless, loose

soils as encountered in secondary tillage practices, the soil physical property, cohesion (C), approaches zero. Lastly soil to metal friction depends more on moisture content of the soil, percentage of clay particles in the soil and surface properties of the metal than on the Coulomb law of friction (18). The law of friction and its requirements does not entirely apply to soil to metal friction. For instance, tillage tools with large contact areas (e.g. mold board plow) have large soil to metal frictional forces that comprise the resultant force. In addition, large frictional soil to metal interfaces can influence the degree of compaction hardening (i.e. plastic deformation) and extend the zone of influence (16).

Gill and Vanden Berg (12) state that the coefficient of soil-metal friction of a nonadhesive soil is normally less than the coefficient of soil-soil friction. In other words less force is required to slide soil over metal than soil over soil.

The use and the determination of frictional forces in soil dynamic studies allows for the analysis of soil reaction forces with relatively simple equations and theories.

2.3.3. Factors Affecting Soil Reaction Forces

The stresses in three directions and frictional forces make up a resultant soil reacting force that must be overcome by the tillage tool to achieve tillage objectives. The resultant is commonly broken down into three components: draft, vertical reaction and lateral reaction. Draft is a major component of the soil reacting force and most important in tillage tool design. Vertical reaction refers to the positive or negative force required to maintain a tillage tool at a particular depth. Lateral reaction refers to the skewing forces

on the implement. The resultant force is a function of tool shape, manner of tool movement, soil conditions and other interferences such as roots and rocks (5, 30).

2.3.3.1. Tool Shape

The designing of tillage tools requires the consideration of macroshape and microshape (18). Macroshape is the overall projection of the tillage tool. The macroshape includes geometric factors such as lift angle, width, lift height, face area, curvature diameter, and edgeshape. These factors are partly responsible for the path the soil must follow, angle of the shear failure plane, and the magnitude of the soil-metal frictional forces. Edgeshape refers to the geometric characteristics of the leading edge of the tillage tool. If a tool has a sharp edge, the tool will cut and pierce the soil mass with very little compression in the zone of influence (12). On the other hand, a blunt or dull edgeshape results in an increased resultant force because of greater compaction. How the tool is beveled or sharpened has a marked difference in the performance (e.g. wear) of the tool. Edgeshape design is determined by the type of tillage objective in mind.

Microshape of the tillage tool refers to the type of metal used and also the surface configuration that will be interfaced with the soil mass. Microshape influences soil-metal frictional forces which may represent up to 30% of the total draft requirement. The smoothness of the metal is usually described by the wetting angle (12). The wetting angle is a measure of the degree to which a water film will adhere to a surface. If the surface is quite open and pitted, a water film will adhere more readily than to a smooth surface such as

polytetrafluoroethylene. The rougher the surface, the larger the soil-metal frictional forces will be. Microshape of the tool and the hardness of the steel also determine the tool's resistance of abrasion and wear.

Thus to obtain the desired soil condition, tool shape becomes of major importance in implement design.

2.3.3.2. Manner of Tool Movement

The manner of tool movement is the speed, or the rate at which a tillage tool moves through the soil mass. The literature states that as the velocity of tillage tool or the rate of shear increases, the resultant force increases (12, 16, 28). The resultant force increases because of the development of greater shear stresses, and frictional forces. Frictional forces increase as a result of greater normal loads on the engaging surfaces. As well, more kinetic energy is applied to the movement and acceleration of soil around or over the tool (18, 23).

The manner of tool movement also refers to the passive or active action the tillage tool has. A passive tool is a tool that requires no energy requirements other than what is used to overcome the resultant soil reaction (e.g. plows, disks, sweeps). An active tool usually has an additional energy input used to reduce the draft or to obtain a desired soil condition (e.g. rotary cultivator, vibratory cultivation).

The design for the manner of tool movement is governed by current tillage objectives and tillage practices.

2.3.3.3. Soil Conditions

Within the soil mass there exists cohesive and adhesive forces.

A cohesive force is the result of attraction of like molecules or particles to each other while an adhesive force is the result of attraction of unlike molecules to each other. Cohesion is an important component of soil strength and both cohesion and adhesion influence frictional forces.

Soil strength is the ability or capacity of the soil to resist external forces (12). Therefore the greater the soil strength the greater the resultant soil reaction. Soil strength cannot be directly measured. Shear tests, compression tests, tensile tests and combinations of these tests are used as indicators and illustrate properties of soil strength (27). Soil strength generally means shear strength and shear strength is made up of the resistance of a soil to be displaced, the frictional resistance to movement between the individual soil particles, cohesive forces and adhesive forces (19). Soil strength is mostly influenced by soil factors such as moisture content, density, organic matter content, structural composition and particle size distribution (13).

Moisture content determines the adhesion due to moisture films within the soil mass. Adhesion develops from moisture tension and the surface tension of water on the surface of the soil particle. There is an optimum moisture content at which all soils have their greatest strength. The plastic limit is used to describe the moisture content of a particular soil at the soil's greatest level of strength. The plastic limit is a function of the particle size and void ratio. If a soil is dominantly made of smaller clay particles, the soil will have a greater surface area, a greater amount of voids and consequently greater adhesive and cohesive attractive forces. The void ratio

depends on the degree of compaction of the soil particles. The greater the degree of compaction or density the greater the soil strength (23, 24). The void ratio also determines whether the soil will plastically flow or fail by other methods. For each soil there is a critical void ratio that determines whether or not a soil will flow. If a loose soil has a void ratio above the critical void ratio the soil will flow when stressed. If a stressed soil compacts or maintains a constant volume during manipulation the soil overcomes its interlocking strength by flowing. However if a soil increases in volume while being stressed, the soil fails by fracturing and shearing of bonds within the soil. Therefore in dense soils more energy is used to fail the soil along failure planes then the energy required to fail a loose soil by flowing (20, 21, 24). Consequently reducing soil strength is not a major tillage objective in secondary tillage operations as it is in primary tillage.

The organic matter content and state of aggregation also influence soil strength. As the amount of organic matter increases, the soil strength decreases because of the weakening of cohesive bonds. If the state of aggregation or the structural condition is friable, the soil strength is less (10). Consequently a tillage objective should be to control soil factors such that a good soil tilth is maintained, not only for better plant growth but also to reduce soil strength.

2.3.3.4. Scouring

Scouring or the lack of scouring is a very special condition that happens at the soil-metal interface. Scouring is defined as the shedding or self-cleaning action of the soil sliding over the metal (12). The factors influencing scouring are the coefficient of soil-

metal friction, the coefficient of soil-soil friction, the approach angle of the tool, cohesion of soil particles to one another, adhesion, tool shape and the rate at which soil is accelerated over the tool (8, 12,18, 26).

Scouring will occur as long as frictional resistance at the soil-tool interface is less than the resistance at a parallel soil-soil interface (18). When the adhesion between the tool and the soil is greater than the cohesion within the soil, the failure and sliding takes place within the soil resulting in a nonscouring situation. A nonscouring situation is a build up or congestion of soil in a low pressure area on the face of the tillage tool. This congested soil may or may not be static.

A nonscouring situation is a major problem in areas with highly adhesive soils (i.e. sticky clays). Generally a nonscouring tillage tool has a greater draft requirement due to larger frictional sliding forces.

2.3.3.5. Penetration

In tillage operations, penetration is linked to initial soil strength and soil condition. A cultural definition of penetration is the ability to use a tillage tool at a desired depth to obtain a stated objective. The ability to penetrate depends on how large a vertical reaction on the tillage tool is required to maintain the desired depth.

A common occurence in tillage operations is the formation of a compacted layer near the surface due to repeated operations with blunt tillage tools and wheeled vehicles. A compacted layer near the surface can be an ideal seedbed and a moisture barrier to control

evaporation. But a long standing plow sole (i.e. compacted layer) tends to impede root development and deep percolation within the soil (4, 26). This compacted layer in subsequent tillage operations results in an increased penetration resistance (11). As a result of penetration problems, special tillage tools have been developed to fracture compacted layers and aid penetration of subsequent tillage.

2.3.4. Analysis of the Soil Reaction

According to the literature the best way to describe a force system in tillage dynamics is with the use of three mutually perpendicular forces and three corresponding moments about the line of action of these force (15, 31). The three forces are the draft, vertical reaction, and the lateral reaction. The corresponding moments are rolling moment, yawing moment and pitching moment. By using these six components, a force system can be analyzed and quantitatively determined. The six components can be used to formulate one resultant force and one resultant moment (31). The vector force and the vector couple make up the wrench which locates the axis of the resultant with respect to the tool.

2.4. Summary

The objectives of tillage entirely govern the analysis and design of tillage tools. Being that the soil is a diverse and changing medium, the perfect tillage tool for all soils is impossible to design. The best that can be done is to follow the guidelines set out by the literature and strive for the ultimate objectives.

Under semi-arid farming conditions, new techniques had to be developed to cope with erosion control and water conservation. To accomplish these techniques, secondary tillage tools were developed.

Secondary tillage tools were also developed to be used for a refined tillage operation (i.e. seedbed preparation) under various farming conditions.

The failure, deformation and movement of soil by tillage tools is the result of complex, interrelated failure theories. A major portion of the total soil reacting force is the result of overcoming shear and compressive strength of the soil. Internal soil particle frictional forces, soil to soil frictional forces and soil to metal frictional forces make up the remainder of the resultant soil reaction. The soil to metal frictional forces are the most crucial in the design of scouring tillage tools.

The factors that affect the soil reacting force are tool shape, manner of tool movement, soil conditions, scouring and depth of penetration. The void ratio is of particular concern in determining the soil strength of loose soils. These factors are composed of numerous interacting variables that can further influence the soil reaction force. The six components of a force system can be used to formulate the wrench which is one resultant force and one resultant moment. The wrench actually gives the location of the resultant vector on the tillage tool with respect to the origin. For the most part, draft is still the major concern in tillage tool design.

3. EXPERIMENTAL DESIGN AND PROCEDURE

3.1. Factors and Levels

Listed in Table I are the factors and levels used in this experimental study. The five factors or variables in the study are; soil-site, depth, rod shape, velocity and rod speed. Three replicates were used to statistically validate the results. McKibben and Berry (22) recommend that a minimum of three replicates should be used for tillage experiments.

Three different soil sites were chosen in Central Alberta for the experiment. Using soil-site as a variable the results would have a greater application to other localities.

Two depths were chosen in the range of depths commonly used by rod weeders. Depth was chosen as a factor to see if the draft would increase as depth of tillage increases for secondary tillage operations as it does for primary tillage operations, but more importantly to ascertain the interactions with depth (25). A depth of 5 cm represents a typical seedbed preparation depth and a depth of 8 cm represents a typical weed control depth for a rod weeder.

Two geometric shapes were chosen for the study mainly to see if there was any advantage of one shape of rod over another. According to the literature, tool shape is a significant factor in the design of a tillage tool. The dimensions and shapes chosen represent typical rod shapes and dimensions in use. Mild steel was chosen rather than high carbon steel rods as used by the industry, because of its machinability. The experimental study concentrates on the soil reacting forces on an isolated segment of rotating rod (i.e. 470 to 500 mm long) and does not include the boots and shanks. Further

TABLE I: FACTORS AND LEVELS OF STUDY

Factors	Symbols	Levels
Soil Site	T1	Silt Loam
	T2	Clay Loam
	T3	Silty Clay Loam
Depth	D1	5 cm
	D2	8 cm
Rod Shape	S1	Round Rod
	S2	Square Rod
Velocity	V1	4.8 km/h
	V2	7.2 km/h
	V3	9.6 km/h
Rod Speed	R1	54 rpm
	R2	108 rpm
	R3	162 rpm
	R4	216 rpm
	R5	270 rpm

studies will have to be done to find out what part the support arms play in the total soil reaction force for a rod weeder. From a survey of rod diameters and dimensions used by the industry a mean round rod diameter of 22.2 mm and a mean square rod dimension of 22.2 mm was chosen for the experiment.

Three ground speeds were chosen to see if the draft increases for secondary tillage operations as it does for primary tillage operations when the rate of travel or the rate of increasing shear increases the soil strength (32). The interactions of ground speed with the other main effects would also be of importance in the analysis of a rotating rod. Speeds of 4.8, 7.2 and 9.6 km/h cover the range that rod weeders are generally operated at.

Most rod weeders rely on a ground wheel drive to rotate the rod. Therefore the rod speed is a function of the ground speed. Rod speeds were determined for various commercial units for a range of ground speeds. The five levels of rod speed chosen exceed the range at which the rod generally rotates. Rod speed factor was chosen to see if there is any significant difference among them and to see if manner of tool movement is a significant design factor for secondary tillage tools. Being that the rod speed is a function of ground speed, a rod index (i.e. ratio of the ground speed of the rod (m/sec) to the peripheral velocity (m/sec)) was calculated to see if it would indicate an optimum.

3.2. Experimental Design

The most suitable experimental design for this study was a split plot due to the distance between soil-sites. Consequently soil-site and blocks (replicates) were analyzed with less precision than the

other main effects. The remaining sixty combinations were randomized within each replicate block at each site.

3.3. Equipment and Facilities

The multicomponent sensor and data acquisition system has been detailed by Harrison (15). Photographic Plate No. 1 illustrates the field unit. Shown is the multicomponent test unit attached to the tractor, power plant, cable leads and data acquisition van.

To supply an independent drive for the various rod speeds, a twelve volt d-c motor and a 90^{o}, 20 to 1 reduction gear box was attached to the active frame (Photo Plate No. 2). Power for the electric motor was supplied by the tractor battery. To obtain the various rod speeds, a chain and sprocket drive system was used. Photo Plate No. 3 illustrates the five sprocket drive combinations between the reduction box shaft and the jack shaft, the tension idler and the final drive from the jack shaft to the rod drive.

To collect data on the forces acting on the rod, furrow openers were placed in front of the rod support arms. Photo Plate No. 4 shows the placement of the disks on the passive frame, so that a furrow opening preceded the rod support arms. Gauge wheels were used in regulating the depth.

The active frame was isolated from the passive frame by six load cells. Signals from the six load cells were transmitted using 20 meter cables to the data acquisition system. Data from the load cells and two auxillary channels was recorded on coded paper tape. The two auxillary channels were used to monitor ground speed and rod speed. Small d-c generators were attached for this purpose to the hub of the gauge wheel and the jack shaft, respectively.

Plate 1: Testing equipment and field apparatus

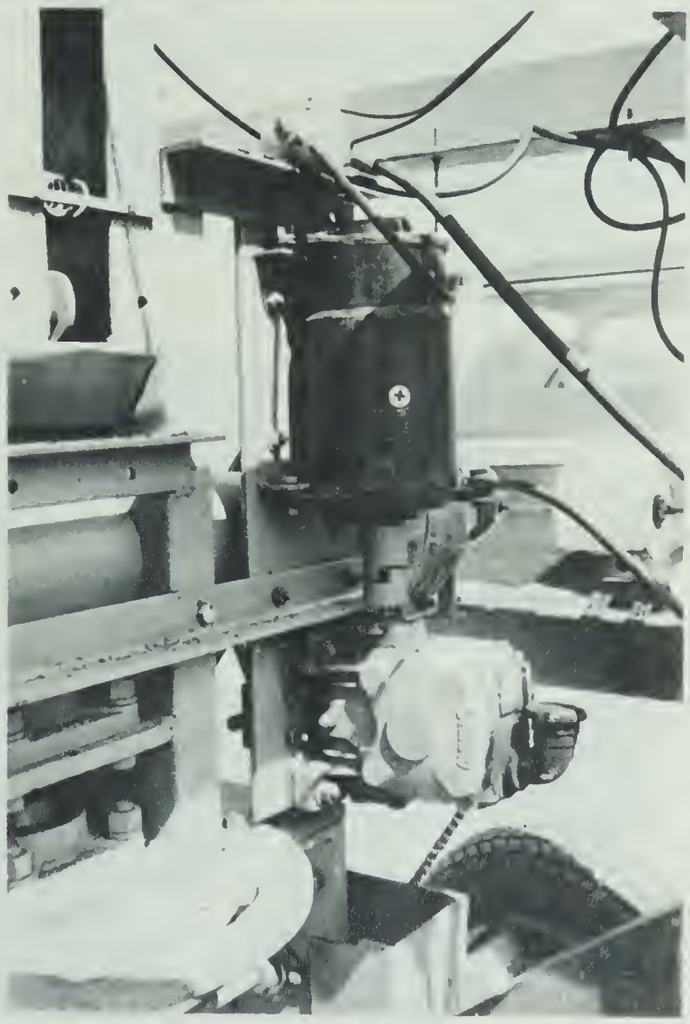


Plate 2: Location of rod apparatus on active frame

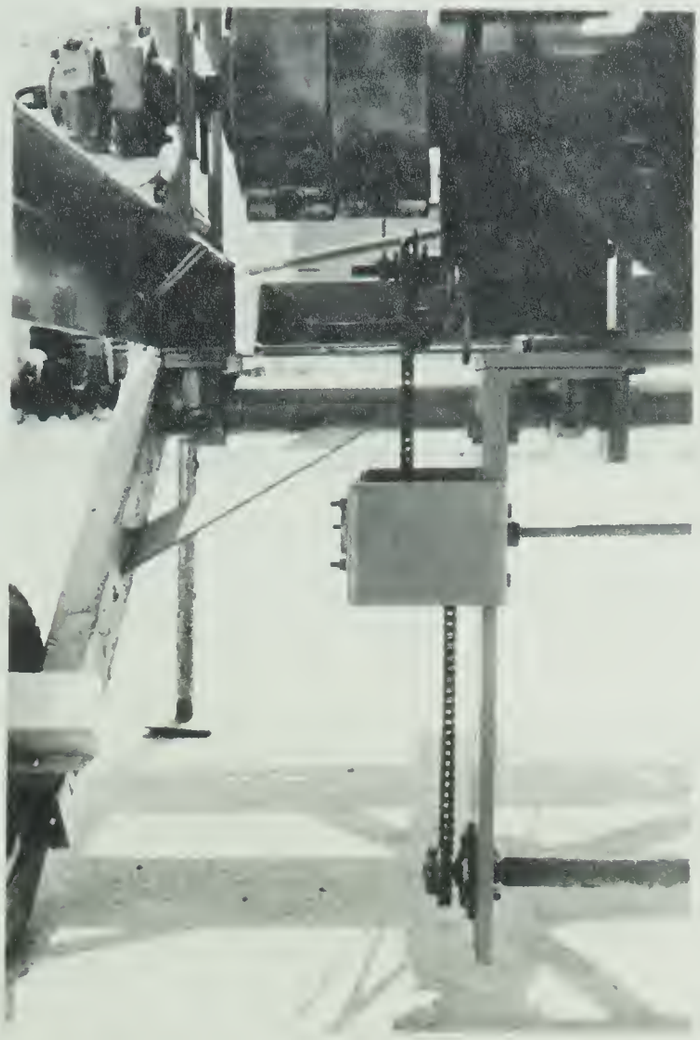


Plate 3: D-C motor and reduction box

Plate 4: Jack shaft sprockets

Other equipment and facilities used were; a gamma-ray density probe, soil analysis lab, and the computer facilities of the University.

3.4. Field Procedure

All soil sites had a common history of standing barley stubble. The initial primary tillage was done with a heavy duty cultivator using 410 mm sweeps on 300 mm centres at a depth of 12 to 15 cm for each site. This operation was followed later by a shallow cultivation (i.e. 5 to 8 cm) and harrowing to spread windrows of straw and to level the site. This was deemed to be a typical primary tillage practice which precedes the use of a rod weeder in the cultural practice of summerfallowing in Alberta.

The sub plot (i.e. random series of runs) was completed within one day to eliminate variability of moisture. The series consisted of the sixty possible combinations of factors and was the limiting factor in the determination of the size of experimental study. The data for each combination was sampled at half second intervals for a distance of 27 to 30 meters. Upon completion of the series, sixteen sample readings of the bulk density were taken and eight sample cores were taken for determining the moisture content. The bulk density readings were taken with hand-held gamma ray transmission equipment using the procedure noted by Soane et al (29). Both sets of samples were taken through the tillage zone to a depth of 10 cm.

Upon completion of the study, soil samples were taken from each soil-site for determining particle size analysis. Four replicate samples were taken from each site to ensure accuracy in the analysis. Particle size analysis was performed using the hydrometer method according to ASTM standards (3).

3.5. Data Acquisition and Processing

Upon completion of the field data collection, the data was transferred from coded paper tape onto MTS file by the use of an optical reader. Next the data was adjusted by conversion factors or calibration constants. Means were then calculated from the observations taken and then transferred from random order to a desired matrix. Previously prepared library programs on APL were then applied to the matrix to determine the analysis of variance and selected means. Upon determination of the significant main effects and interactions the results were then tabulated or plotted with the aid of the Wang 600 calculator system. At this time the location of the wrench axis was determined and plotted. Lastly a rod index was determined and the torque requirements were determined from the wrench axis deagrams.

4. RESULTS AND DISCUSSION

4.1. Analysis of Variance

Table II lists the results of the analysis of variance for the split-plot design used in the experiment. For each possible main effect and interactions a F-test was carried out. The columns in the table are the mean square values and the resulting F-ratio. The Error 1 term is used in calculating the F-ratio for replicates and soil-sites. The Error 2 term is used in calculating the F-ratio for all the remaining sources of variation. The analysis of variance determines which source of variation has a significant effect on draft and the vertical reaction.

4.2. Soil-Sites and Replicates-Main Effects

The results of the textural classification analysis and the monitored results of moisture content and dry bulk density of the respective soil-sites over the three replicates are illustrated in Table III on Soil Characteristics. Neither the blocks nor the soil-sites tested significant even though the differences were large (see Table IV). This can be partially attributed to the position of the factor in the experimental design.

From Table III the variation in textural classification, moisture content and bulk density is relatively small for the three soil sites. The moisture content consistently decreased and bulk density consistently increased over the three replicates for each soil.

Some additional factors that were observed were: the amount of vegetative cover, the type of vegetative cover and the amount of straw mulch varied widely among the three sites. These in turn affected the soil strength, the amount of obstructions (e.g. roots) and the penetra-

TABLE II: ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Draft MS	Draft F	Vertical MS	Vertical F
Blocks (b)	2	8.224	1.19	2.340	4.06
Soil Site (T)	2	2.916	<1	1.453	2.52
BT (Error 1)	4	6.916		.5756	
Subtotal	8				
Depth (D)	1	.3281	3.53	.06214	2.86
Shape (S)	1	.8873	9.54***	.3071	14.1 ***
Velocity (V)	2	1.853	19.9 ***	.6276	28.8 ***
Rod Speed (R)	4	1.762	18.9 ***	.4014	18.4 ***
TD	2	.1995	2.14	.00432	<1
TS	2	.4531	4.87**	.10	4.60*
TV	4	.06660	<1	.01164	<1
TR	8	.1634	<1.76	.03261	1.50
DS	1	.00045	<1	.01657	<1
DV	2	.000401	<1	.0087	<1
DR	4	.05235	<1	.0323	1.48
SV	2	.01483	<1	.0332	1.53
SR	4	.07678	<1	.05365	2.47*
VR	8	.04609	<1	.02273	1.04
TDS	2	.02358	<1	.01211	<1
TDV	4	.03903	<1	.01251	<1
TDR	8	.06494	<1	.00828	<1
TSV	4	.2174	2.34	.05477	2.52*
TSR	8	.0788	<1	.02829	1.30

TABLE II (con't): ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Draft MS	Draft F	Vertical MS	Vertical F
TVR	16	.06974	<1	.01838	<1
DSV	2	.05521	<1	.01524	<1
DSR	4	.2525	2.71*	.03327	1.53
DVR	8	.1868	2.01*	.02291	1.05
SVR	8	.06305	<1	.02218	1.02
TDSV	4	.03495	<1	.00754	<1
TDSR	8	.1037	1.12	.01881	<1
TDVR	16	.09612	1.03	.02067	<1
TSVR	16	.08564	<1	.01545	<1
DSVR	8	.1077	1.16	.01799	<1
TDSVR	16	.05462	<1	.01301	<1
Error 2	354	.09303		.02176	
Total	539				

* Significant to the 5% probability level
** Significant to the 1% probability level
*** Significant to the .5% probability level

TABLE III: SOIL CHARACTERISTICS

(a) Texture

Soil Site	% Clay	% Sand	% Silt	Texture Classification
Soil 1	24	17	59	Silt Loam
Soil 2	27	22	51	Clay Loam to Silt Loam *
Soil 3	37	18	45	Silty Clay Loam

(b) Moisture Contents and Bulk Density

Soil	Block	Moisture Content** (%)	Bulk Density** (g/cm^3)
Silt Loam	1	28.9	1.14
	2	28.5	1.15
	3	22.7	1.20
Clay Loam	1	30.6	1.13
	2	20.9	1.22
	3	20.6	1.22
Silty Clay Loam	1	34.2	1.09
	2	24.9	1.17
	3	21.8	1.21

* Will be referred to as clay loam
** Calculated on dry basis

TABLE IV: MEANS OF THE MAIN EFFECTS FOR DRAFT AND VERTICAL REACTION

Factors	Levels	Draft (N/m)	Vertical Reaction (N/m)
Block	1	730	260
	2	920	390
	3	1200	290
Soil Site	Silt Loam	800	280
	Clay Loam	960	460
	Silty Clay Loam	1100	400
Depth	5 cm	910	390
	8 cm	960	370
Rod Shape ***	Round	970	400
	Square	890	350
Velocity ***	4.8 km/h	870	320
	7.2 km/h	880	370
	9.6 km/h	1100	440
Rod Speed ***	54 rpm	1200	470
	108 rpm	960	400
	162 rpm	870	360
	216 rpm	840	340
	270 rpm	350	320

*** significant at the 0.5% probability level

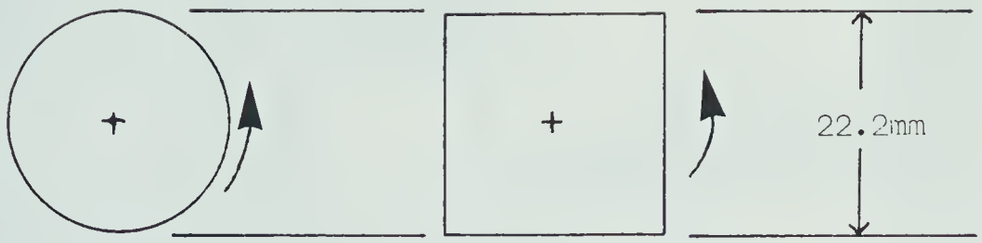
tion capabilities of the rod.

4.3. Rod Shape-Main Effect

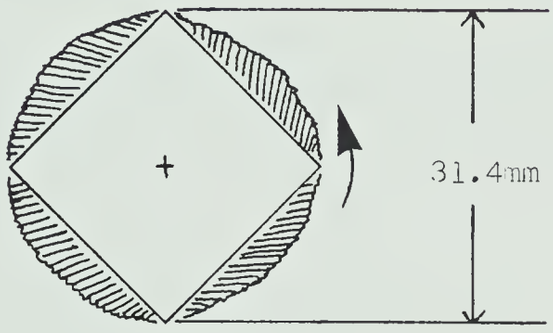
The rod shape has a highly significant effect on draft and vertical reaction (Table II). The square rod required 80 N/m less draft and 50 N/m less vertical reaction than the round rod (Table IV). This is an unexpected result because the square rod has a larger effective rod diameter (see Figure 2). Though both rods were either 22.2 mm diameter or a 22.2 mm square, the square rod actually had a maximum effective diameter of 31.4 mm. As cited in the literature review, the soil reacting forces should increase as the lift height (i.e. effective rod diameter) increases. Therefore the decrease in draft and vertical reaction for the square rod must be due to the rotation of the rod.

It was observed that the square rod did not scour and self-clean like the round rod. Photo Plate No. 5 illustrates the build up of soil on the flat sides of the square rod. Figure 2(b) illustrates that when the soil adheres to the faces of the square rod, the rod takes on a circular shape with an effective diameter of at least 31.4 mm. Most likely the nonscouring occurs because the faces of the square rod are low pressure areas. Also the frictional resistance and the adhesion of the soil to the metal surface must be greater than the frictional resistance and cohesion within the soil. As will be noted later there is an important interaction of shape with the soil-site factor.

In order to achieve a passageway for the rod, some of the soil must flow up and over the rod forming a dam of material over the tillage tool, as first described by Krause (20), and some of the soil



(a)



(b)

Figure 2: Round rod and square rod effective diameters

Plate 5: Soil adhering to square rod

must pass under the rod. This plane of separation between the soil passing over and under the rod is illustrated in Figure 3. The plane of separation seems to be a cutting plane by a very dull blade and can be described as a theoretical line where all the particles above the line pass over the rod and all the particles below the line pass under the rod. In other words it is the division line of least resistance for the particles. The particles passing over the rod are subject to shear stresses and compressive stresses. The particles passing under the rod undergo compressive stresses. As cited in the literature review, the more plastic deformation or compaction that takes place, the more energy that is consumed. This could partially account for the round rod having greater draft and vertical reaction than the square rod. More soil must pass under the round rod resulting in more compaction than does the square rod. Therefore the plane of separation must be a greater distance from the center line for a square rod than a round rod.

The reason for differences in the location of the plane of separation is most likely due to two interrelated factors. In the first place the peripheral velocity of the nonscouring square rod is always greater than the peripheral velocity of the round rod for any given rod speed. The second factor is that the coefficient of soil-soil friction is usually greater than the coefficient of soil-metal friction in nonadhesive soils. Consider the aggregates of soil at the instantaneous moment of contact with the rod. The aggregates and the rod are subject to frictional forces on each other. The amount of aggregates and how the aggregates are accelerated or moved over the rod depends on the coefficient of soil-soil friction or coefficient

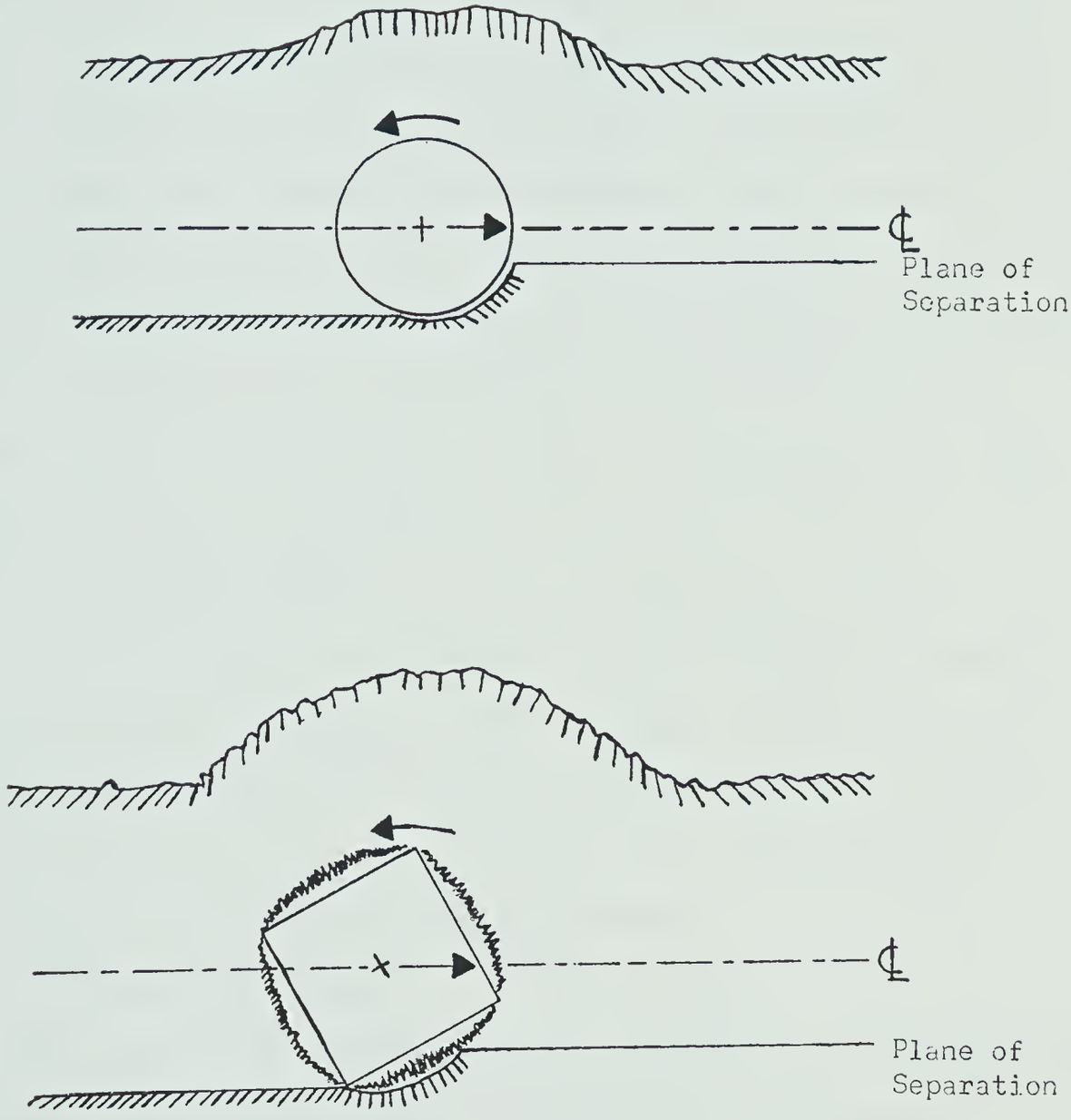


Figure 3: Action of round and square rod

of soil-metal friction and the peripheral velocity of the rod. The square rod having a combination of a greater peripheral velocity and essentially a soil-soil interface (i.e. with greater coefficient of friction) would accelerate an aggregate more effectively over the square rod than the round rod. A greater coefficient of friction would tend to increase the distance of the plane of separation from the center line, thus requiring less energy in the compaction of the soil going beneath the rod. An observation of the two rods in action showed that the square rod was consistently more aggressive than the round rod. With the square rod, the soil was agitated more thoroughly and the weeds more effectively uprooted. By observation and by tabulated results (Table IV) the square rod showed greater penetration capabilities under adverse conditions.

4.4. Velocity-Main Effect

As the ground speed increases both draft and vertical reaction increase due to an increase in shear strength. As the velocity doubled from 4.8 km/h to 9.6 km/h the draft increased by 21% and vertical reaction increased by 36% (Table IV). Therefore soil strength is a function of the rate of shear.

4.5. Rod Speed-Main Effect

Rod speed has a noticeable effect on the draft and the vertical reaction. Both the draft and the vertical reaction decreased at a decreasing rate as the rod speed was increased (Table IV). The rod speed determines the peripheral velocity of both types of rods and with an increase in the peripheral velocity, more soil particles flow over the rod rather than be subjected to compaction below the rod, thereby decreasing the draft and vertical reaction.

4.6. Depth-Main Effect

The main effects for depth are not significant (Tables II and III) which supports the theory that for secondary tillage operations, under stubble mulch conditions, the soil strength is uniform in the tillage zone.

4.7. Rod Shape/Soil Site Interaction

The interaction of the rod shape and the soil-site for the draft and the vertical reaction tested significant and is indicated in Figures 4 and 5 by warpage of the face planes. Both rod shapes show an equal response to the clay loam soil site for draft and vertical reaction. This is due to the adverse site conditions. Both rods had difficulty in penetrating and maintaining penetration in the tall weed growth and the heavily developed root system that increased the soil strength and created obstructions in the path of the rod. The response for the silt loam and silty clay loam sites for the draft and the vertical reaction complies with the previously noted comments with respect to the main effects for the two rod shapes.

4.8. Rod Speed/Rod Shape Interaction

For the square rod, as the rod speed increases, the vertical reaction decreases at a diminishing rate suggesting some optimum beyond the range of the study (see Figure 6), whereas for the round rod, as the rod speed increases, the vertical reaction decreases to a minimum then increases again.

The significant response in Figure 6 is revised in Figure 7 by using best fit curve techniques as detailed by Harrison (14). Figure 7 illustrates how the best fit curves diverge. The round rod tends

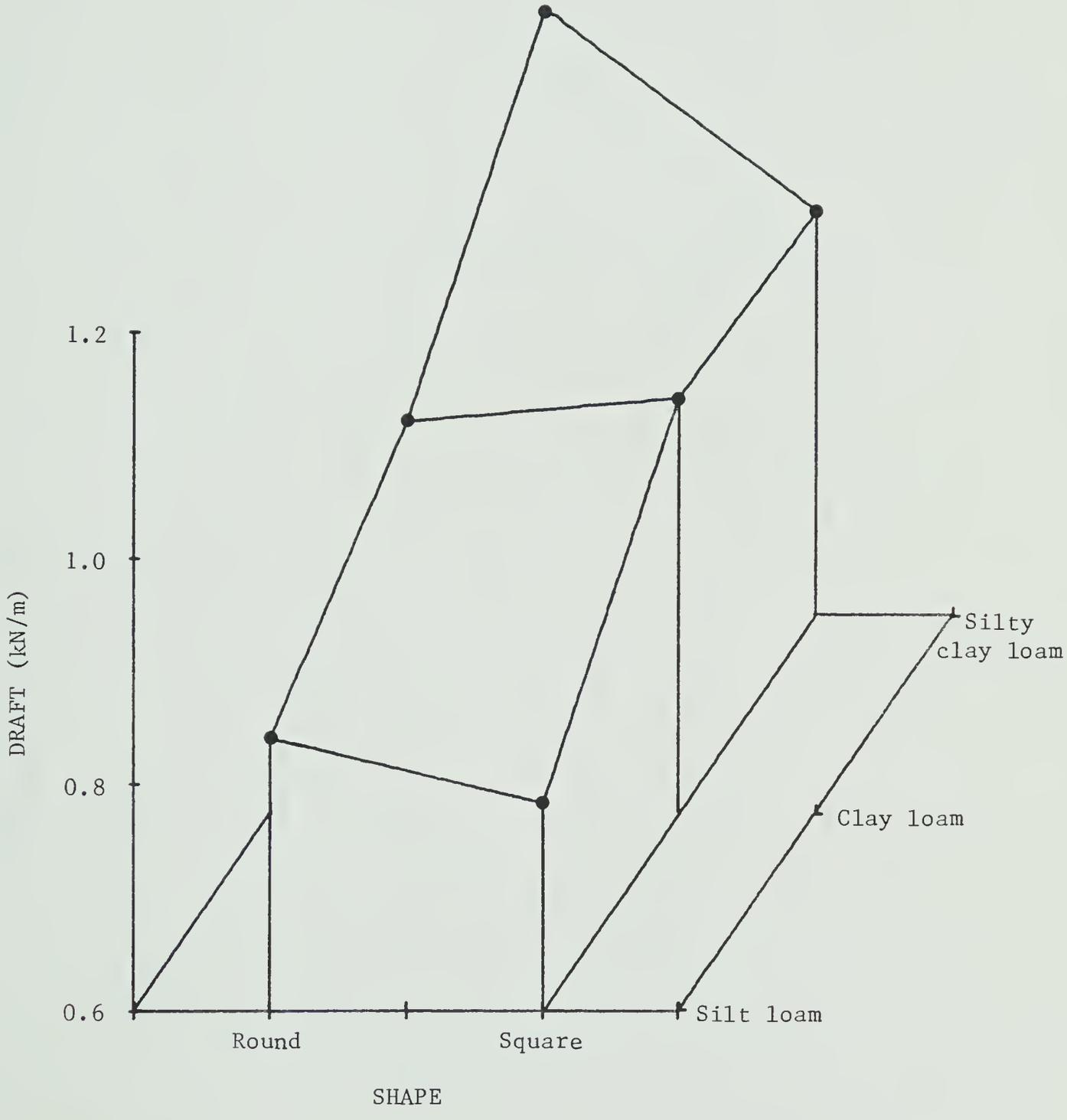


Figure 4: Shape-soil interaction for draft.

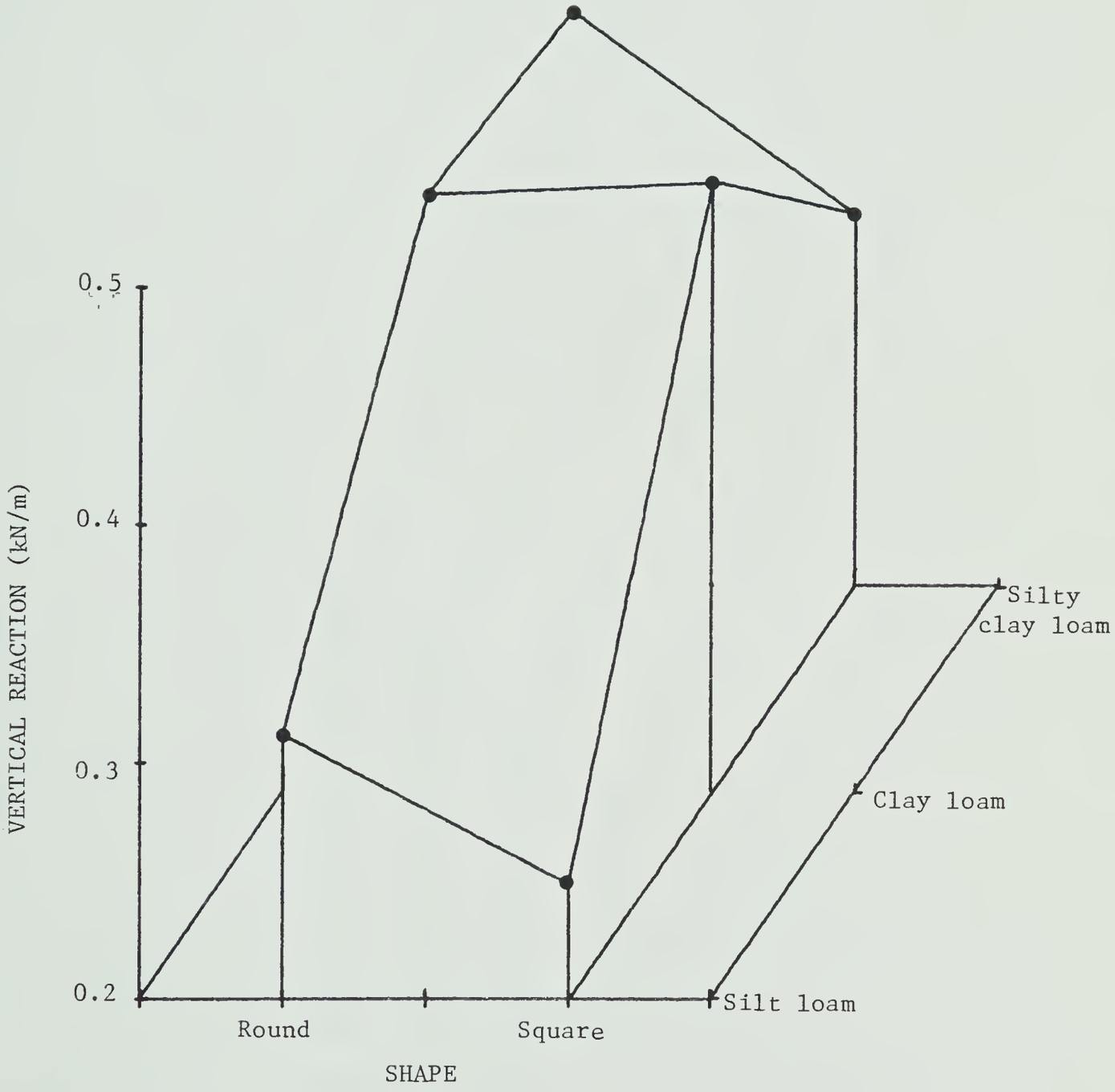


Figure 5: Shape-soil interaction for vertical reaction.

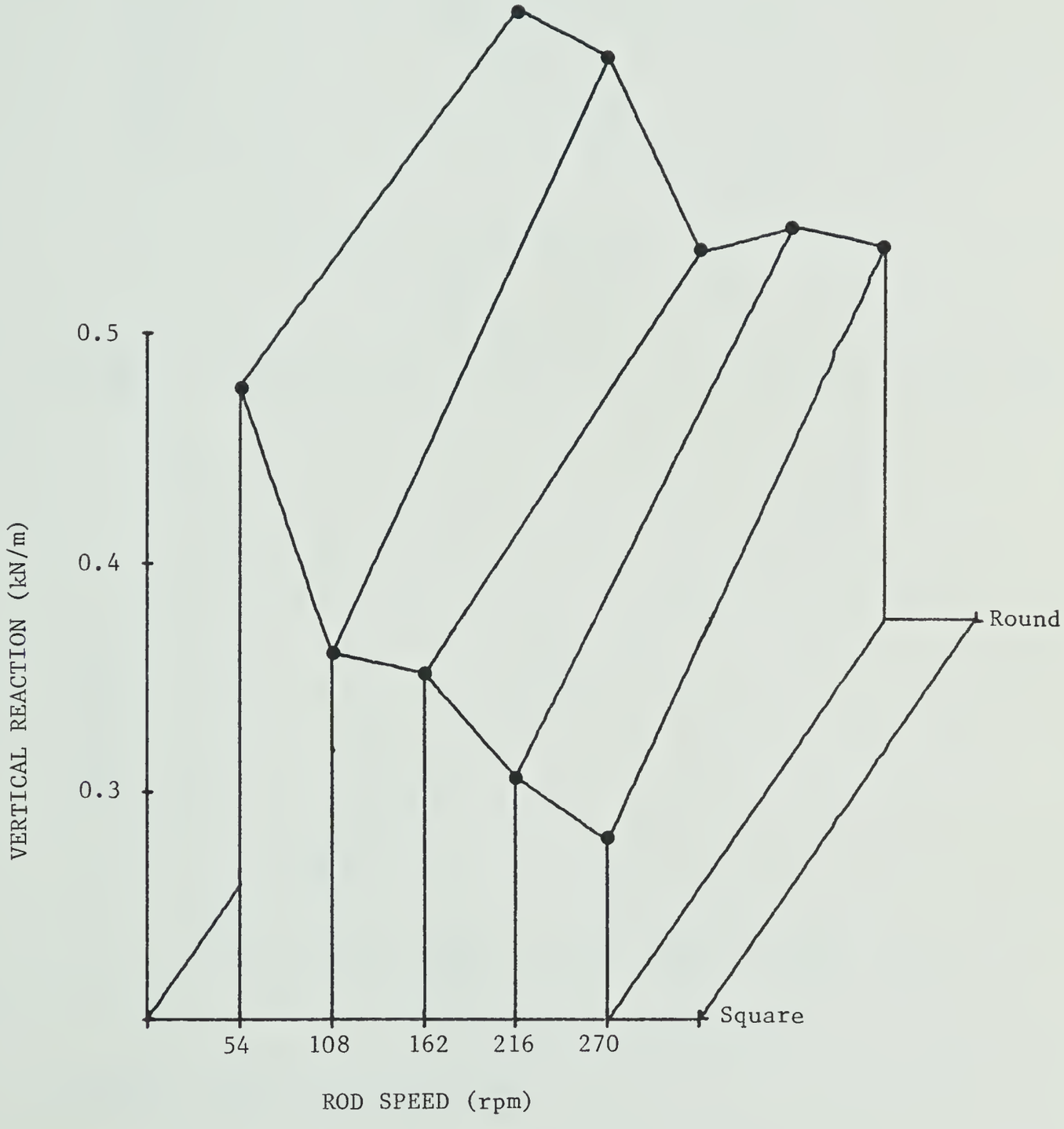


Figure 6: Rod speed-rod shape interaction for vertical reaction.

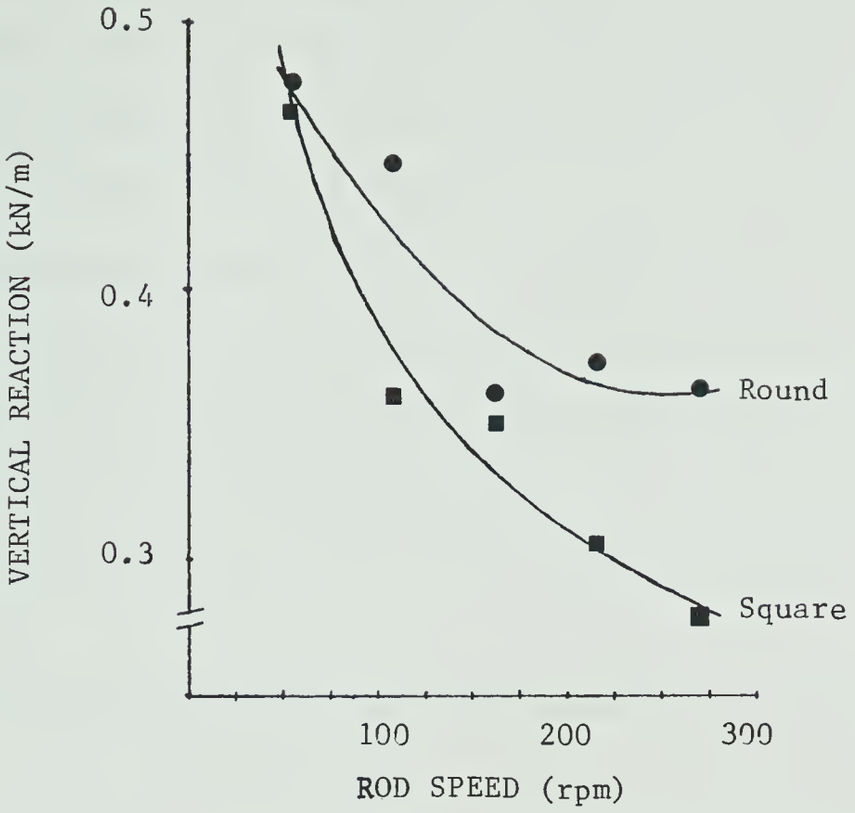


Figure 7: Rod speed versus vertical reaction for round and square rods

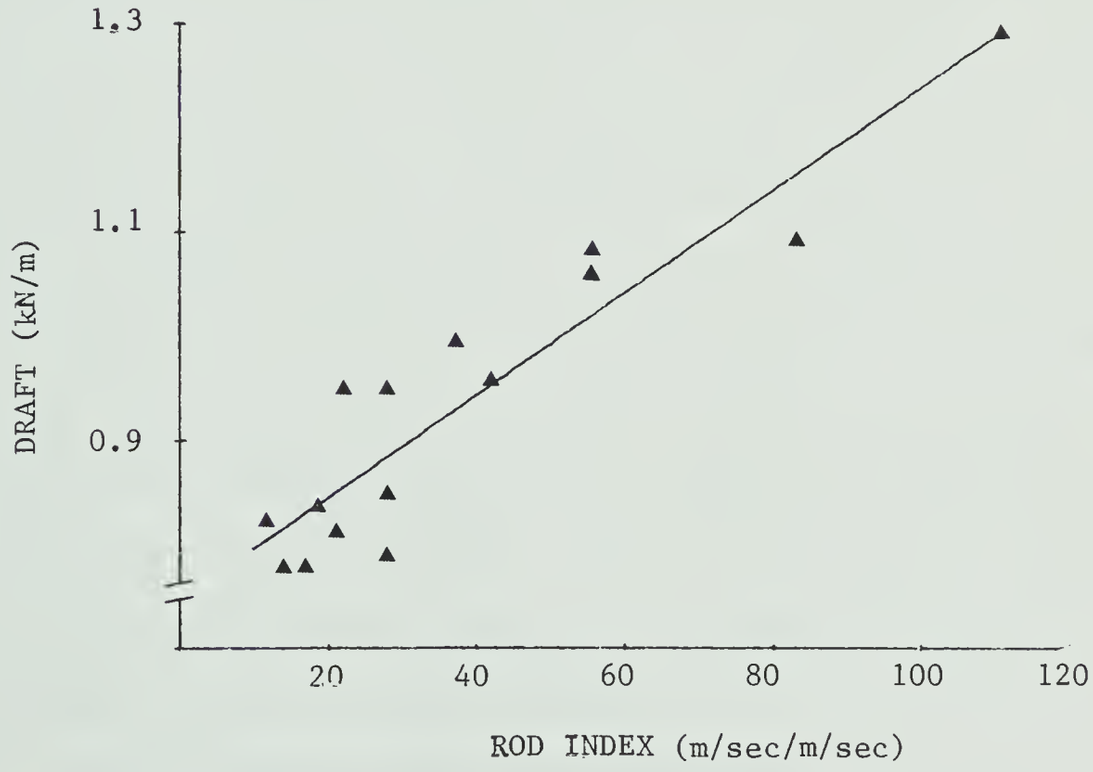


Figure 8: Rod index versus draft

to show an optimum rod speed of 260 rpm for a minimum vertical reaction. The square rod on the other hand has not yet reached an optimum rod speed for vertical reaction over the range of rod speeds chosen for this study. An increase in rod speed decreases the vertical reaction more rapidly for the square rod than the round rod. This is due to a greater coefficient of friction at the soil-soil interface on the square rod than the coefficient of friction at the soil-metal interface on the round rod. Hence the square rod is better able to make use of its frictional forces to decrease the vertical reaction.

As previously stated for most conventional rod weeders, rod speed is a function of ground speed. In Figure 8 the rod index (ratio of the ground speed (m/sec) to the peripheral velocity of the rod (m/sec)) is plotted against draft (kN/m). Again a best fit curve was plotted for the data. For rod indexes between 11 and 40 there is a wide dispersion of data points; consequently, a linear line had the highest correlation. This implies that further investigation for testing lower rod indexes is warranted. From Figure 8, draft can be minimized at lower rod indexes for the range of ground speeds and rod speeds tested. Seeing that the ground speed is more or less fixed to conventional operating velocities (4.8 km/h to 9.6 km/h) the rod speed becomes the only variable. Therefore rod speeds of greater than 270 rpm should be tested in order that an optimum rod index can be determined that will minimize the draft.

4.9. Velocity/Soil-Site/Rod Shape Interaction

The significant velocity/soil-site/rod shape interaction for vertical reaction is illustrated in Figure 9. The interaction is

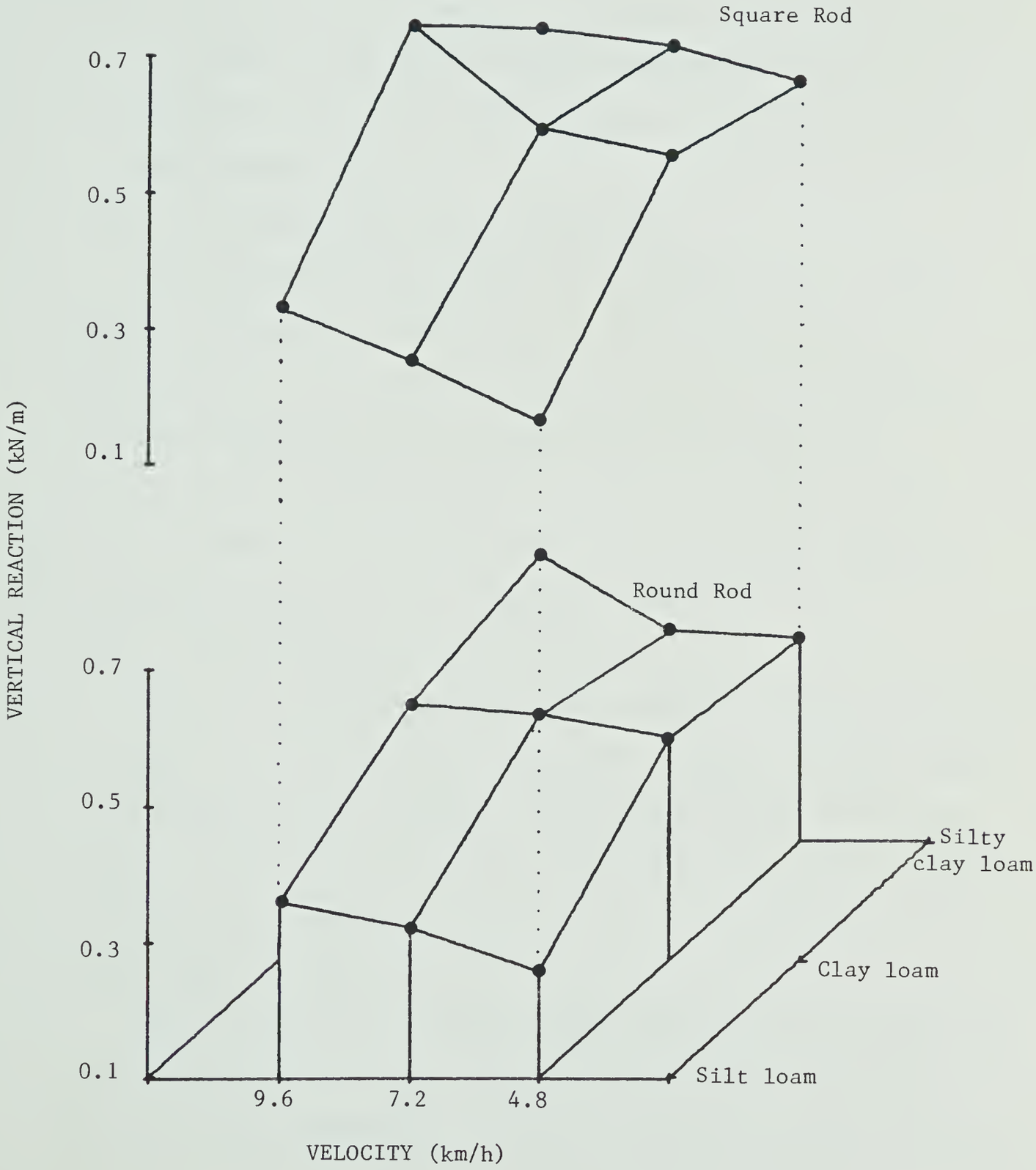


Figure 9: Velocity-soil-shape interaction for vertical reaction

largely due to the differential response for the round rod and square rod planes at 9.6 km/h and the silty clay loam soil-site. As previously stated and observed the round rod had considerably more difficulty in maintaining penetration than the square rod at the silty clay loam soil site. The round rod had a tendency not to self-clean as well, to run out of the ground and eventually plug up. The square rod was able to maintain penetration because of its more aggressive shape and its effective use of soil to soil friction at higher ground speeds.

4.10. Rod Speed/Rod Shape/Depth Interaction

The rod speed/rod shape/depth interaction for draft is illustrated in Figure 10. This significant differential response for draft occurs for the change in depth for the round rod at 270 rpm. At the 8 cm depth the round rod tends to an optimum speed of 162 rpm for minimum draft. At the 5 cm depth the round rod has not yet reached an optimum rod speed for minimum draft. There is no apparent reason for this differential response.

4.11. Rod Speed/Velocity/Depth Interaction

The rod speed/velocity/depth interaction for draft is illustrated in Figure 11. The significant differential response for draft occurs for a change in depth, a change in rod speed of 108 rpm to 162 rpm and at a travel rate of 7.2 km/h.. Again there is no apparent reason for this type of response.

4.12. Wrench or Screw Axis

The location of the resultant force and the resultant moment for a tillage tool is the wrench. Illustrated in Figures 12 through 15 is the side elevation of the rod and the location of the resultant

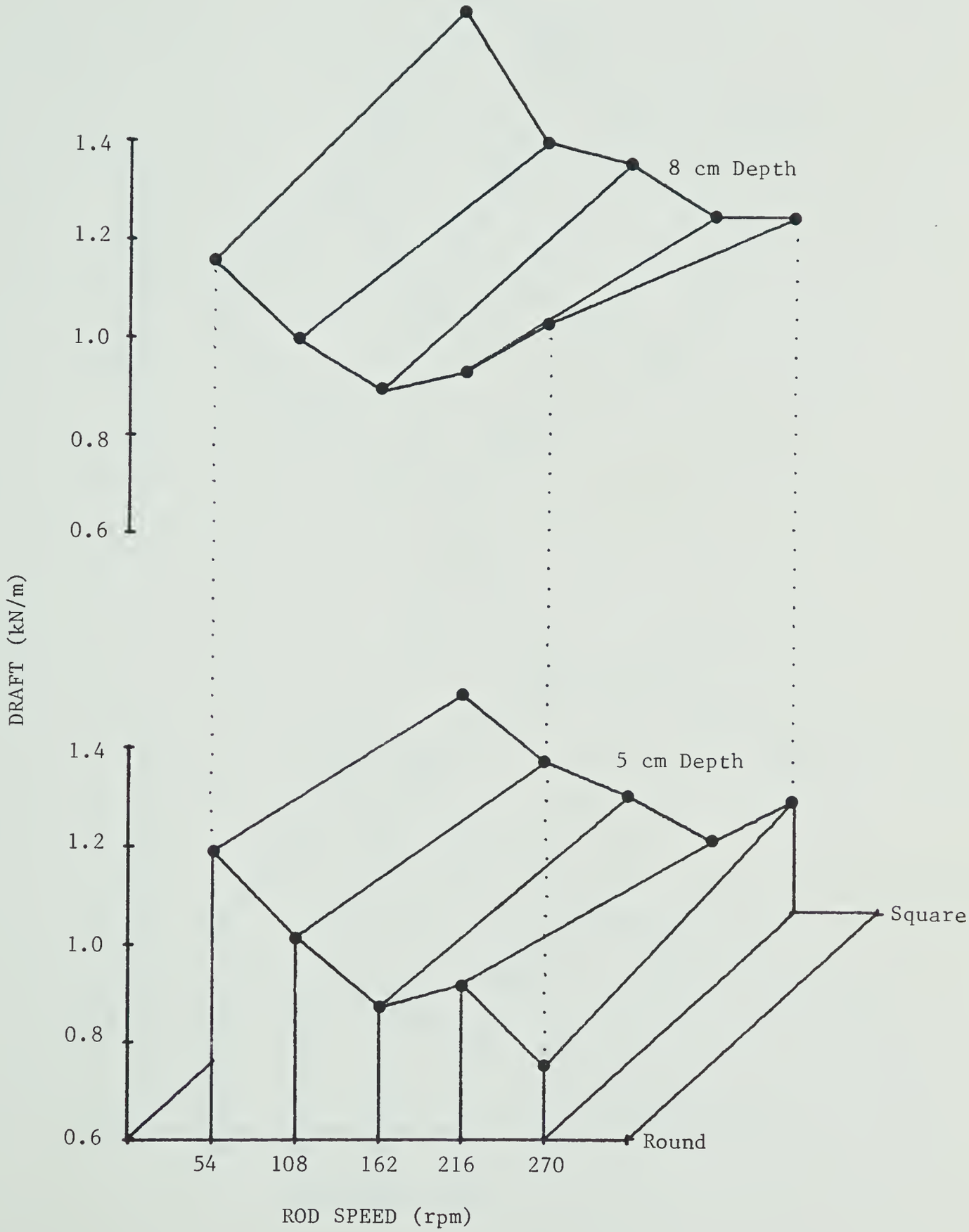


Figure 10: Rod speed-shape-depth interaction for draft.

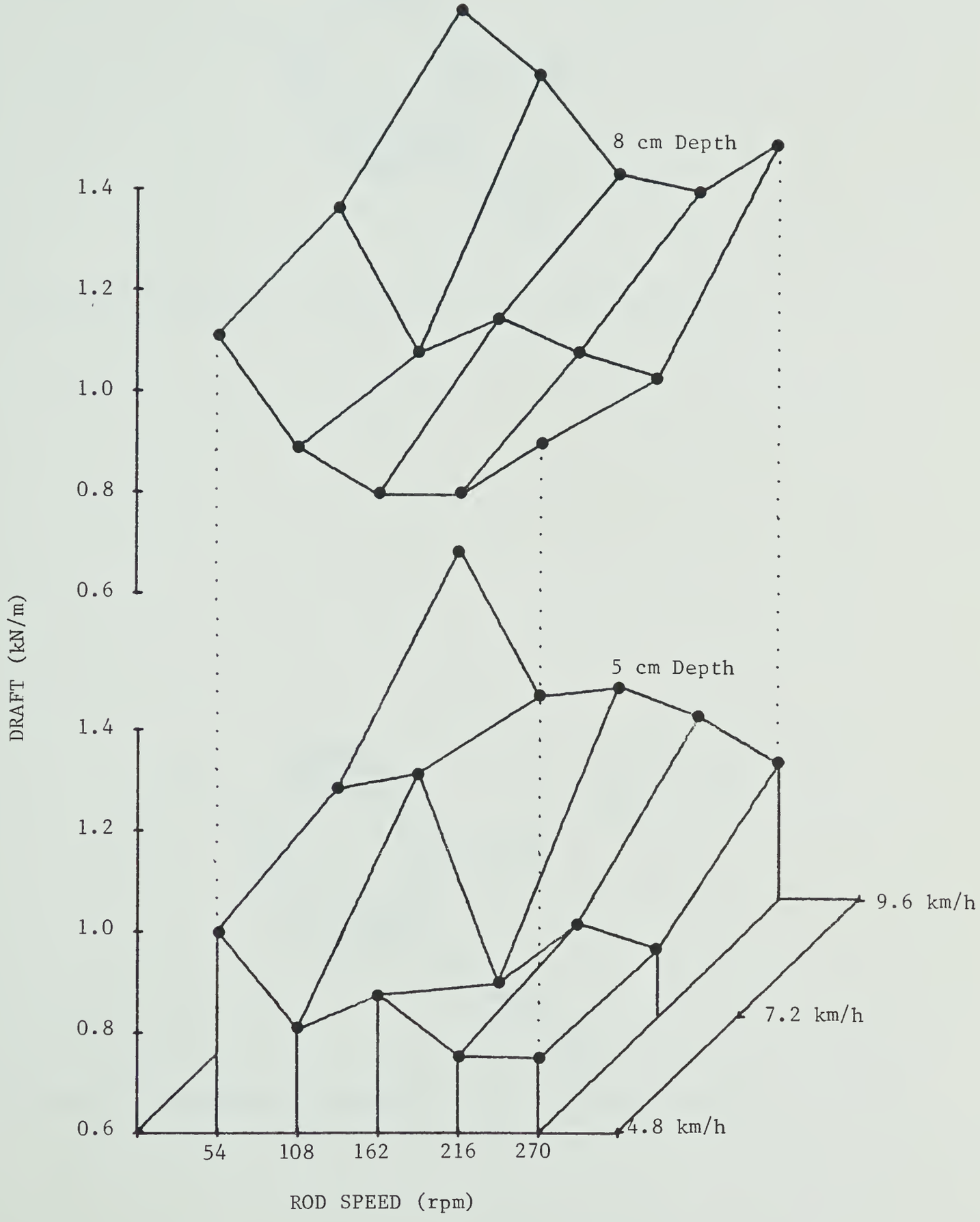


Figure 11: Rod speed-velocity-depth interaction for draft.

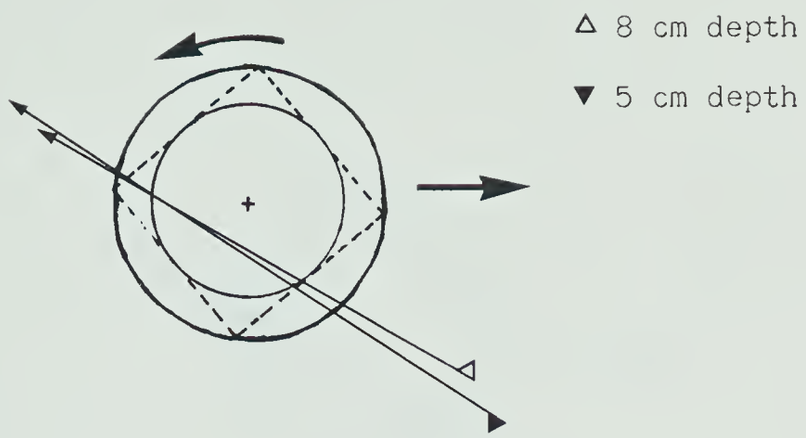


Figure 12: Wrench axis location for 8 cm and 5 cm depth

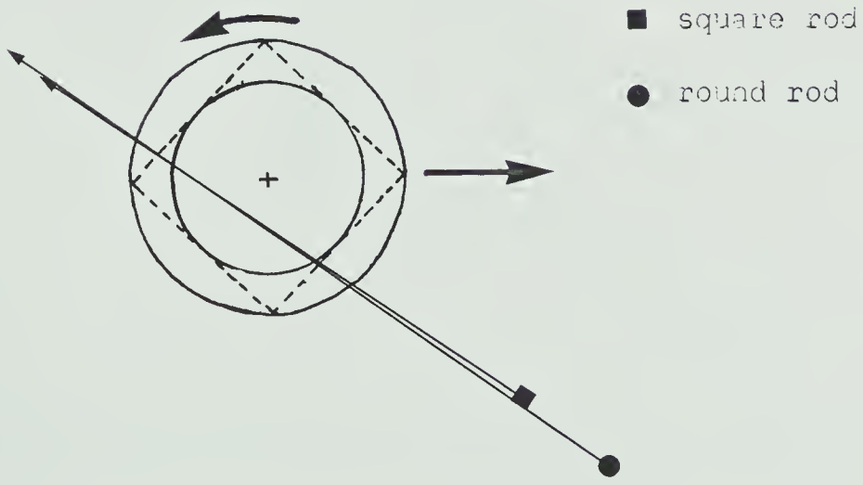


Figure 13: Wrench axis location for round and square rods

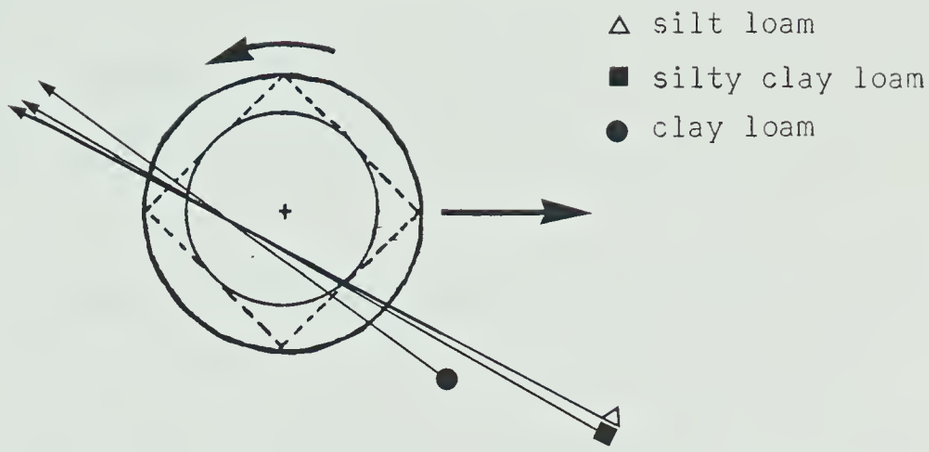


Figure 14: Wrench axis location for silt loam, silty clay loam, and clay loam soil sites

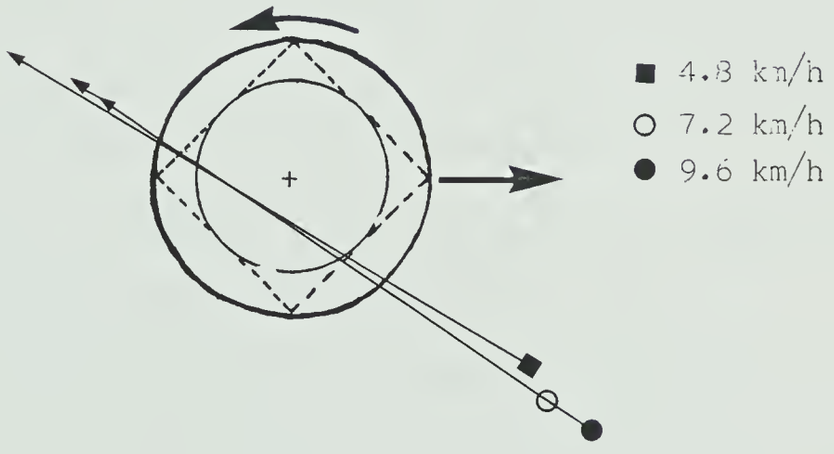


Figure 15: Wrench axis location for 4.8 km/h, 7.2 km/h, and 9.6 km/h

vector force for each level of the factors in the experiment. In each of the diagrams the round rod diameter, the direction of travel, the direction of the rod rotation, and the effective diameter of the square rod is shown.

The location of resultant vector force varies little among the factors and levels, though the magnitude of the resultant vector does.

From the wrench axis diagrams and the magnitude of the wrench the torque for the main effects can be determined (see Table V). The moment arms of the vector was scaled from the figures and used to calculate the torque. From the torque values a power torque requirement (W/m) was determined. Also illustrated in Table V are the draft values (N/m) and power requirements (W/m) due to draft.

When comparing the drawbar and shaft power requirements the latter is very small. The clay loam soil with the greatest penetration problems had the largest torque of the three soils. The torque requirement is greater at a packing depth than at a weed control depth. Even though the square rod has a greater effective diameter than the round rod the torque is less for the square rod. Torque increases as velocity increases due to greater soil strength and as the rod speed increases the torque decreases.

There is a possibility that the location of the wrench axis is a function of the location of the plane of separation. In other words there is some relationship between the location of plane of separation and the point where the projected resultant vector intersects the surface or effective surface of the rod.

TABLE V: MAIN EFFECTS: MEANS OF THE TORQUE AND POWER REQUIREMENTS

Main Effect	Level	Draft (N/m)	Drawbar Power 7.2 Km/hr (W/m)	Resultant |Q| (N/m)	Torque (N-m/m)	Shaft Power (W/m)
Soil Site	Silt Loam	796.1	1590	850.2	2.8	27
	Clay Loam	958.1	1920	1073	4.3	35
	Silty Clay Loam	1047	2100	1140	3.8	33
Depth	5 cm	909.1	1820	999.7	3.8	33
	8 cm	958.4	1920	1040	3.5	31
Shape	Round	974.3	1940	1078	4.0	33
	Square	893.2	1780	973.6	3.6	31
Velocity	4.8 km/h	866.3		935.9	3.3	29
	7.2 km/h	884.5	1760	971.7	3.7	31
	9.6 km/h	1050		1152	4.4	38
Rod Speed	54 rpm	1146	2300	1253	4.5	52
	108 rpm	960.5	1920	1054	3.8	44
	162 rpm	871.2	1740	952.6	3.4	39
	216 rpm	843.6	1680	921.7	3.3	38
	270 rpm	847.4	1700	917.4	3.1	36

5. SUMMARY AND CONCLUSIONS

The following summary and conclusion with respect to the rod were derived from the preceding results, discussions and observations:

(i) The soil conditions prior to tillage affected the soil strength and therefore the draft and penetration of the rod weeder.

(ii) The draft and vertical reaction did not change appreciably as the depth of tillage increased because of the loose, well aggregated soil tilth that was maintained throughout the experiment.

(iii) The round rod had a greater draft with inferior penetration than did the square rod because more soil passed under the round rod causing more compaction and using more energy. The amount of soil that goes over and under the rod (i.e. location of the plane of separation) is determined by the peripheral velocity of the rod, the soil-metal and the soil-soil friction forces.

(iv) As the travel rate of the rod weeder increased, the greater was the draft and poorer was the penetration due to the increase in shear strength with rate of loading.

(v) There appeared to be an optimum rod speed for minimum vertical reaction which depends on the rod shape. The rod speed determines the peripheral velocity of the rod and hence the amount of compaction.

(vi) The draft appeared to increase with an increase in rod index.

(vii) The round rod packed the soil more which may be an

advantage for seedbed preparations.

(viii) The resultant vector force passed through the rod at nearly the same location for all factors. The shaft power per meter of rod ranges from 27 W/m to 52 W/m and is negligible when compared to the drawbar power which varied from 1680 W/m to 2300 W/m.

6. RECOMMENDATIONS

As a result of this study the following recommendations could help in further analysis of the soil dynamics for rod weeders:

(i) A wider range of soil conditions should be included to enhance the application of the results.

(ii) Other geometric shapes and sizes made of varying materials should be investigated to further minimize draft requirements.

(iii) The investigation of rod speeds above 270 rpm or rod indexes of less than 11.0 should be conducted.

(iv) A study on rod supporting shanks and boots should be included.

7. LITERATURE CITED

1. Agriculture Statistics Yearbook. 1975. Alberta Agriculture. Agdex 853-3: 8,77.
2. Aron, I. 1972. Crop Production in Dry Regions. Leonard Hill Books, London. Vol. 1: 417-436.
3. ASTM Standards. 1970. American Society for Testing and Materials, Philadelphia, Pa. Part 19, D422: 70-80.
4. Baver, L.D., Gardner, WLHL, and Gardner, W.R. 1972. Soil Physics. 4th Edition, John Wiley and Sons, Inc. New York. 87-124.
5. Chisholm, R.S., Porterfield, J.G., and Batchelder, D.G. 1972. A Soil Bin Study of Three-dimensional Interference Between Flat Plate Tillage Tools Operating in an Artificial Soil. Trans. ASAE, Vol. 15: 43-48.
6. Collins, E.R. and Lalor, W.F. 1973. Soil-Bin Investigation of a Deep-Working Tillage Tool. Trans. ASAE, Vol. 16: 29-33.
7. Currence, H.D., and Lovely, W.G. 1970. The Analysis of Soil Surface Roughness. Trans. ASAE, Vol. 13: 710-714.
8. Eidet, J.H., Marley, S.J., Buchele, W.F., and Schafer, R.L. 1975. A Universal High Speed Moldboard Plow Bottom. For Presentation at Annual Meeting of ASAE, Davis, California. Paper No. 75-1035.
9. Fenster, Charles R. 1973. Conservation Tillage Proceedings of a National Conference by the Soil Conservation Society of America. Des Moines, Iowa: 202-206.
10. Fox, W.R., Deason, D.L., and Wang,L. 1967. Tillage Energy Applications. Trans. ASAE, Vol. 10: 843-846.

11. Gill, W.R. 1968. Influence of Compaction Hardening of Soil on Penetration Resistance. Trans. ASAE, Vol. 11: 741-745.

12. Gill, W.R. and Vanden Berg, G.E. 1968. Soil Dynamics in Tillage and Traction. Agriculture Handbook No. 316, Agricultural Research Service, USDA, Washington, D.C.

13. Gudta, D.P., and Pandya, A.C. 1967. Behavior of Soil Under Dynamic Loading: Its Application of Tillage Implements. Trans. ASAE, Vol. 10: 352-358.

14. Harrison, H.P. 1973. Dimensional Analysis for Vibratory Tillage Tools. Can. Agric. Eng., Vol. 15, No. 2: 75-78.

15. Harrison, H.P. 1975. Instrumentation of a Multi-Component Sensor. Trans. ASAE, Vol. 18, No. 4: 765-769.

16. Hendrick, J.G., and Gill, W.R. 1973. Soil Reaction to High Speed Cutting. Trans. ASAE, Vol. 16: 401-403.

17. von Hulst, H. 1971. Tillage and Seeding Practices and Machines for Crop Production in Semiarid Areas. FAO Agric. Development Paper No. 92.

18. Kepner, R.A., Bainer, R., and Barger, E.L. 1972. Principles of Farm Machinery. AVI Publishing Company, Inc., Westport, Connecticut: 106-140.

19. Kézdi, Arpád. 1974. Handbook of Soil Mechanics. Elsevier Scientific Publishing Col, New York, N.Y., Vol. 1: 183-188.

20. Krause, R. 1974. Some Results from Soil Bin Investigations. Paper No. 74-1586. ASAE, Annual Winter Meeting.

21. Lambe, T.W. and Whitman, R.V. 1969. Soil Mechanics. Massachusetts Institute of Technology. John Wiley and Sons, Inc. New York: 143-144, 443.

22. McKibben, E.G., and Berry, M.O. 1952. The Value of Replications in Research. Agricultural Engineering, Vol. 33: 792, 798.

23. Olson, D.J., and Weber, J.A. 1965. Effect of Speed on Soil Failure Patterns in Front of Model Tillage Tools. For Presentation at Farm, Construction and Industrial Machinery Meeting of the SAE, Milwaukee, Wisconsin. Paper No. 650591.

24. Panwar, J.S., and Siemens, J.C. 1972. Shear Strength and Energy of Soil Failure Related to Density and Moisture. Trans. ASAE, Vol. 15: 423-427.

25. Payne, P.C.J. 1956. The Relationship between the Mechanical Properties of Soil and the Performance of Simple Cultivation Implements. Jour. of Agric. Eng. Res., Vol. 1: 23-46.

26. Payne, P.C.J., And Fountaine, E.R. 1954. The Mechanism of Scouring for Cultivation Implements. Technical Memorandum No. 116. National Institute of Agricultural Engineering.

27. De Rooch, Bernard, and Cooper, A.W. 1967. Relation Between Propagation Velocity of Mechanical Waves Through Soil and Soil Strength. Trans. ASAE, Vol. 10: 471-474.

28. Rowe, R.J., and Barnes, K.K. 1961. Influence of Speed on Elements of Draft of a Tillage Tool. Trans. ASAE, Vol. 4(1): 55-57.

29. Soane, B.C., Campbell, D.J., and Herkes, S.M. 1971. Hand-held Gamma Ray Transmission Equipment for the Measurement of Bulk Density of Field Soils. Jour. of Agric. Eng. Res. Vol. 16: 146-156.

30. Sohne, W. 1956. Some Principles of Soil Mechanics as Applied to Agricultural Engineering. Grundlager der Landtechnik 7: 1-27, Illus, (Natl, Inst. Agr. Engin. Eng. Translation 53).

31. Taylor, P.A. 1967. Field Measurement of Forces and Moments on Wheatland Plow Disks. Trans. ASAE, Vol. 10: 762-768.

32. Telischi, B., McColly, H.F. and Erickson, E. 1956. Draft Measurement for Tillage Tools. Agric. Eng., Vol. 37: 605-608.

33. Vomocil, J.A., and Chancellor, W.J. 1967. Compressive and Tensile Failure Strengths of Three Agricultural Soils. Trans. ASAE, Vol. 10: 771-774.

8. APPENDIX: DRAFT (L), VERTICAL REACTION (V), LATERAL REACTION (S), PITCHING COMPONENT, ROLLING COMPONENT AND YAWING COMPONENT IN kN/m. THE PITCHING MOMENT (P), ROLLING MOMENT (R) AND THE YAWING MOMENT (Y) ARE:

P = PITCHING COMPONENT X 630 mm

R = ROLLING COMPONENT X 584 mm

Y = YAWING COMPONENT X 636 mm

TABLE I: DRAFT (kN/m) - BLOCK 1

T	D	S	V	R1	R2	R3	R4	R5
			V1	0.3808	0.3582	0.2349	0.3931	0.0613
		S1	V2	0.3017	0.3392	0.3907	0.392	0.3942
			V3	0.5329	0.6588	0.5503	0.5557	0.3033
	D1		V1	0.4976	0.3572	0.4735	0.1144	0.2748
		S2	V2	0.4229	0.441	0.2943	0.3091	0.3734
			V3	0.7507	0.9213	0.7798	0.5529	0.687
T1			V1	0.3449	0.3617	0.3684	0.338	0.2953
		S1	V2	0.7018	0.2377	0.4812	0.4445	0.4808
			V3	0.8037	0.7427	0.7845	0.6251	0.5114
	D2		V1	0.5533	0.4796	0.3237	0.2985	0.7129
		S2	V2	0.4752	0.4428	0.3243	0.2877	0.2708
			V3	0.7469	0.6399	0.5437	0.7653	0.8229
			V1	1.063	0.9808	0.7487	0.9534	0.5825
		S1	V2	0.8374	1.005	0.9483	0.8192	0.6836
			V3	0.8608	1.002	0.8398	0.7254	0.5385
	D1		V1	1.325	0.853	1.338	1.24	0.7523
		S2	V2	1.206	0.7631	0.8824	0.8728	0.8125
			V3	1.134	1.40	1.212	0.6218	1.009
T2			V1	1.107	0.9601	1.312	0.8882	0.7196
		S1	V2	0.9093	0.9931	0.92	1.008	0.6367
			V3	1.125	0.9816	0.9446	0.8388	0.8322
	D2		V1	1.128	0.9681	1.052	1.021	1.007
		S2	V2	0.9706	1.229	1.471	0.8409	0.8789
			V3	1.299	1.497	1.390	1.096	1.092
			V1	0.6941	0.7033	0.3111	0.5153	0.7076
		S1	V2	0.7549	1.233	0.4728	0.6966	0.5723
			V3	0.6251	0.7113	1.160	1.084	0.6963
	D1		V1	0.757	0.6546	0.4696	0.6135	0.3177
		S2	V2	0.7825	0.8719	0.6343	0.5784	0.9483
			V3	0.8346	1.117	0.8681	0.5699	0.8515
T3			V1	0.8845	0.6969	0.5584	0.5644	0.5394
		S1	V2	0.9949	0.6163	0.5025	0.7856	0.745
			V3	0.9983	0.7228	0.7343	0.6293	0.7048
	D2		V1	0.7452	0.6834	0.5508	0.6756	0.5164
		S2	V2	0.9477	0.7541	0.8854	0.7555	0.7212
			V3	1.096	1.008	0.9154	0.7842	0.6584

TABLE I (con't): DRAFT (kN/m) - BLOCK 2

T	D	S	V	R1	R2	R3	R4	R5
			V1	0.3176	1.151	0.2925	0.3002	1.236
		S1	V2	0.684	0.5001	1.019	0.3892	0.3144
			V3	0.6632	0.8542	0.689	0.3533	0.1871
	D1		V1	0.9398	0.2833	1.411	0.3646	0.2879
		S2	V2	0.4755	0.4287	0.3332	0.2964	0.492
			V3	0.8417	0.2061	0.3418	0.3206	0.8639
T1			V1	1.077	0.6372	0.5869	0.4738	0.7864
		S1	V2	0.6069	0.7817	1.317	1.348	0.4571
			V3	1.051	0.6659	0.175	0.3784	0.6018
	D2		V1	0.7435	1.401	0.6183	0.4109	0.5372
		S2	V2	0.7768	0.5236	0.5125	0.5167	0.371
			V3	0.957	0.3932	0.3949	0.691	0.4351
			V1	1.222	0.5405	0.6122	0.6913	0.4241
		S1	V2	1.374	1.032	0.2581	0.3825	0.4411
			V3	1.489	0.7135	0.7939	0.3392	0.1351
	D1		V1	0.7612	0.5329	0.6802	0.3195	0.2437
		S2	V2	0.4524	0.6608	0.4587	0.5949	0.4451
			V3	0.9548	0.8902	0.5133	0.9659	1.121
T2			V1	0.9744	0.6747	0.8943	0.8552	0.6821
		S1	V2	0.9926	0.6338	0.4227	0.218	0.5144
			V3	0.836	1.188	0.5841	1.248	1.192
	D2		V1	1.064	0.8093	0.6868	0.5735	0.5832
		S2	V2	0.9471	0.2433	0.6911	0.4571	0.3981
			V3	1.166	0.7331	1.147	0.7738	0.4819
			V1	1.410	1.266	2.622	1.769	0.825
		S1	V2	2.107	1.942	0.4059	1.606	0.57
			V3	2.372	2.119	1.764	2.354	0.5242
	D1		V1	1.977	1.007	0.5223	0.7208	1.169
		S2	V2	1.696	1.869	0.7111	1.023	1.862
			V3	1.769	1.050	0.6884	1.546	0.8091
T3			V1	1.805	1.246	1.227	1.141	2.064
		S1	V2	1.866	1.224	1.44	1.349	2.122
			V3	2.262	2.123	1.352	1.382	2.511
	D2		V1	1.545	0.4594	1.053	1.162	1.132
		S2	V2	2.119	0.6565	1.540	0.9467	1.149
			V3	1.665	1.476	0.5316	0.9648	1.317

TABLE I (con't): DRAFT (kN/m) - BLOCK 3

T	D	S	V	R1	R2	R3	R4	R5
			V1	1.833	1.194	1.400	1.107	1.147
		S1	V2	1.799	1.644	1.026	2.319	1.193
			V3	2.735	1.245	1.577	1.427	1.771
	D1		V1	0.9414	0.8751	1.109	0.9457	0.7684
		S2	V2	1.412	1.430	1.372	0.9502	1.580
			V3	1.984	1.440	1.164	1.659	1.764
T1			V1	1.038	1.027	0.8578	1.070	1.922
		S1	V2	1.132	1.067	0.9116	1.159	1.421
			V3	1.509	1.374	1.276	1.392	1.756
	D2		V1	1.321	1.062	0.8432	0.9795	0.9519
		S2	V2	1.412	0.9506	0.982	0.9624	0.7436
			V3	1.397	1.300	1.285	0.9599	1.032
			V1	1.099	1.058	1.145	1.204	1.265
		S1	V2	1.219	1.427	0.4313	0.6543	1.341
			V3	1.742	1.159	1.685	0.7497	1.569
	D1		V1	0.9301	0.8374	0.8932	1.088	1.084
		S2	V2	0.9652	1.355	1.114	0.9929	0.439
			V3	0.9125	1.180	1.779	1.248	1.183
T2			V1	1.337	1.297	0.8855	1.046	1.014
		S1	V2	1.361	1.200	1.443	1.110	1.642
			V3	1.511	1.252	1.143	1.068	0.9899
	D2		V1	1.626	1.102	1.067	0.7653	0.9532
		S2	V2	1.593	1.272	0.7379	1.053	0.6388
			V3	1.887	1.654	2.057	1.251	1.124
			V1	0.9889	0.8183	0.5726	0.6151	1.504
		S1	V2	1.245	1.189	0.5983	0.706	0.3976
			V3	1.768	0.5387	1.001	1.725	0.8253
	D1		V1	0.9429	1.044	0.8749	0.5849	0.791
		S2	V2	1.214	1.082	0.625	0.514	0.6679
			V3	1.219	1.064	0.9457	0.4606	0.753
T3			V1	1.167	1.112	0.8099	1.320	0.76
		S1	V2	1.048	1.512	1.069	1.284	0.6025
			V3	1.694	1.488	1.068	1.123	1.316
	D2		V1	1.589	0.9717	0.5761	0.6942	0.9267
		S2	V2	1.472	0.8378	0.7902	0.6568	0.5345
			V3	1.178	1.612	1.027	0.7281	1.153

TABLE II: VERTICAL REACTION (kN/m) - BLOCK 1

T	D	S	V	R1	R2	R3	R4	R5
			V1	0.1053	0.1267	0.0954	0.1296	0.0843
		S1	V2	0.1451	0.0858	0.0479	0.1491	0.1716
			V3	0.2636	0.2431	0.1709	0.1487	0.1981
	D1		V1	0.0966	-0.0591	0.0629	0.1166	0.0529
		S2	V2	0.2032	0.0624	0.1288	0.0696	0.1008
			V3	0.3041	0.2747	0.1608	0.1918	0.2749
T1			V1	0.0962	0.1367	0.0785	0.082	0.065
		S1	V2	0.1534	0.1324	0.152	0.1368	0.0629
			V3	0.19	0.1563	0.2288	0.221	0.2397
	D2		V1	0.095	0.0781	0.0906	0.0628	0.257
		S2	V2	0.2267	0.1241	0.0833	0.1154	0.0392
			V3	0.2154	0.2015	0.2173	0.1737	0.151
			V1	0.4726	0.3802	0.3424	0.411	0.2093
		S1	V2	0.4173	0.4916	0.4307	0.3622	0.2405
			V3	0.453	0.5299	0.2995	0.3636	0.2186
	D1		V1	0.5182	0.3632	0.5437	0.4394	0.2452
		S2	V2	0.5107	0.3259	0.4005	0.3302	0.3533
			V3	0.5163	0.5578	0.5243	0.3198	0.4481
T2			V1	0.379	0.3047	0.4182	0.2938	0.1696
		S1	V2	0.3295	0.5127	0.3513	0.2731	0.2631
			V3	-0.3245	0.4558	0.3796	0.3388	0.2782
	D2		V1	0.4385	0.3426	0.3663	0.2518	0.2332
		S2	V1	0.4067	0.4986	0.6378	0.3303	0.3243
			V3	0.6128	0.6189	0.5686	0.3689	0.4211
			V1	0.2552	0.2373	0.1708	0.1864	0.2685
		S1	V2	0.268	0.4557	0.2305	0.2971	0.1694
			V3	0.282	0.3393	0.1692	0.3884	0.2647
	D1		V1	0.2154	0.2354	0.1622	0.1761	0.1494
		S2	V2	0.3575	0.2988	0.2085	-0.0562	0.3394
			V3	0.4621	0.4275	0.3116	0.253	0.2827
T3			V1	0.2814	0.1777	0.223	0.1748	0.1625
		S1	V2	0.3202	0.2783	0.2005	0.2274	0.2226
			V3	0.3836	0.3052	0.2994	0.1148	0.2309
	D2		V1	0.1705	0.2534	0.1724	0.1586	0.1855
		S2	V2	0.3542	0.1939	0.2558	0.2428	0.2778
			V3	0.3331	0.3641	0.3769	0.2432	0.2135

TABLE II (con't): VERTICAL REACTION (kN/m) - BLOCK 2

T	D	S	V	R1	R2	R3	R4	R5
			V1	0.24	0.2705	0.1598	0.1739	0.2851
		S1	V2	0.3693	0.324	0.2345	0.2076	0.2701
			V3	0.3077	0.4079	0.2303	-0.0281	0.1342
	D1		V1	0.3823	0.1473	0.2305	0.2325	-0.0507
		S2	V2	0.2513	0.2215	0.159	0.1437	0.2397
			V3	0.1381	0.1135	0.2467	0.1637	0.2001
T1			V1	0.2422	0.226	0.2939	0.2233	0.31
		S1	V2	0.2858	0.3301	0.2952	0.2722	0.2403
			V3	0.3846	0.2828	0.144	0.0768	0.2342
	D2		V1	0.3488	0.244	0.2495	0.2392	0.2047
		S2	V2	0.2548	0.2313	0.2065	0.3245	0.1783
			V3	0.6501	0.2035	0.1846	0.2209	0.25
			V1	0.5088	0.4688	0.2949	0.4431	0.355
		S1	V2	0.6679	0.4181	0.2587	0.2511	0.3102
			V3	0.3201	0.6055	0.3739	0.2554	0.0817
	D1		V1	0.4629	0.3973	0.3598	0.2085	0.1059
		S2	V2	0.4248	0.5297	0.5243	0.3126	0.2428
			V3	0.6128	0.5148	0.385	0.4106	0.6197
T2			V1	0.566	-0.1755	0.597	0.3472	0.5736
		S1	V2	0.4135	0.6428	0.3388	0.3055	0.4345
			V3	0.4827	0.8011	0.407	0.4852	0.3683
	D2		V1	0.4634	0.308	0.2444	0.2486	0.2653
		S2	V2	0.5866	0.0337	0.3771	0.281	0.2172
			V3	0.7317	0.4293	0.501	0.4112	0.3649
			V1	0.6528	0.5166	0.6189	0.8487	0.3205
		S1	V2	0.727	0.7617	0.182	0.5784	0.2754
			V3	0.7998	1.181	0.7383	0.9748	0.2341
	D1		V1	0.6617	0.3853	0.2288	0.2685	0.4318
		S2	V2	0.7696	0.6684	0.3309	0.5431	0.545
			V3	0.6401	0.5837	0.2782	0.6419	0.2679
T3			V1	0.6336	0.4042	0.3373	0.4572	0.754
		S1	V2	0.7617	0.5415	0.6102	0.5149	0.7923
			V3	0.8496	0.6852	0.6025	0.5561	0.8148
	D2		V1	0.6029	0.1517	0.4643	0.2993	0.3558
		S2	V2	0.5519	0.2676	0.5426	0.3994	0.4154
			V3	0.6357	0.2682	0.0407	0.4125	0.4855

TABLE II (con't): VERTICAL REACTION (kN/m) - BLOCK 3

T	D	S	V	R1	R2	R3	R4	R5
			V1	0.6272	0.4719	0.387	0.523	0.5325
		S1	V2	0.7499	0.6275	0.59	0.8288	0.4775
			V3	1.158	0.6021	0.7184	0.544	0.8057
	D1		V1	0.3267	0.2946	0.3332	0.3249	-0.6422
		S2	V2	0.6127	0.5783	0.4735	0.2999	0.4562
			V3	0.9667	0.4612	0.5462	0.6862	0.6611
T1			V1	0.3637	0.2982	0.3099	0.2301	0.5097
		S1	V2	0.3749	0.4085	0.3859	0.4361	0.6686
			V3	0.5277	0.4888	0.5073	0.4584	0.684
	D2		V1	0.4903	0.2054	0.3093	0.2371	-0.0757
		S2	V2	0.5335	0.361	0.3344	0.3647	0.1952
			V3	0.4075	0.4974	0.4458	0.3402	0.3135
			V1	0.5233	0.6281	0.5244	0.5712	0.5615
		S1	V2	0.6498	0.9482	0.2663	0.46	0.6177
			V3	0.6787	0.6236	0.7722	0.432	0.8574
	D1		V1	0.4874	0.3862	0.4161	0.5581	0.4013
		S2	V2	0.5695	0.6418	0.5917	0.4244	0.2333
			V3	0.5807	0.6143	1.032	0.6568	0.661
T2			V1	0.6186	0.6027	0.4227	0.4366	0.5364
		S1	V2	0.5494	0.6086	0.666	0.5484	0.7079
			V3	0.7844	0.7502	0.6444	0.5724	0.4358
	D2		V1	0.7709	0.4798	0.318	0.3863	0.4358
		S2	V2	0.7749	0.5671	0.3836	0.4357	0.3274
			V3	0.8767	0.8216	0.9647	0.6235	0.4139
			V1	0.4907	0.3278	0.1871	0.2864	0.7386
		S1	V2	0.5571	0.6797	0.2978	0.2068	0.2554
			V3	0.8867	0.2642	0.4981	0.768	0.4057
	D1		V1	0.456	0.4194	0.3813	0.2715	0.3083
		S2	V2	0.5217	0.484	0.2367	0.2946	0.2606
			V3	0.5406	0.513	0.366	0.1183	0.3163
T3			V1	0.5797	0.4354	0.3871	0.5528	0.3045
		S1	V2	0.4791	0.6481	0.4969	0.5345	-0.3267
			V3	0.4635	0.6527	0.4515	0.4867	0.5176
	D2		V1	0.6518	0.342	0.2453	0.3013	0.3325
		S2	V2	0.5121	0.3029	0.3287	0.3024	0.2496
			V3	0.4956	0.6299	0.4271	0.3327	0.47

TABLE III: LATERAL REACTION (kN/m) - BLOCK 1

T	D	S	V	R1	R2	R3	R4	R5
			V1	-0.0126	0.1218	0.0086	-0.006	0.1905
		S1	V2	0.0104	-0.1107	0.0487	0.0565	0.07
			V3	0.2439	0.019	-0.1016	0.0489	0.132
	D1		V1	0.0121	0.0882	0.0838	0.0146	0.038
		S2	V2	0.0685	-0.0302	0.1711	0.1869	-0.0427
			V3	0.116	0.0549	0.0883	0.073	0.0748
T1			V1	-0.0287	0.115	-0.0901	0.054	0.0549
		S1	V2	0.0774	0.0391	-0.0247	0.0701	0.1252
			V3	0.0572	-0.0358	0.0868	0.1125	0.2129
	D2		V1	-0.0006	0.0205	-0.1008	-0.1236	0.1852
		S2	V2	0.1079	0.0077	0.1	0.0132	0.1153
			V3	-0.0176	-0.0057	0.1045	0.13	0.0693
			V1	0.2351	0.1096	0.0992	0.0723	0.0104
		S1	V2	0.339	-0.0377	0.2011	0.1006	0.0395
			V3	0.3375	0.38	0.1244	0.2289	0.1549
	D1		V1	0.268	0.1269	-0.029	0.1652	0.0039
		S2	V2	0.1198	0.1732	0.1325	0.1751	0.092
			V3	0.1666	0.0026	0.2272	0.0885	0.344
T2			V1	0.2554	0.2448	0.1551	0.2555	0.0127
		S1	V2	0.0342	0.0545	0.1158	-0.0179	0.0761
			V3	0.2327	0.0905	0.0678	0.1361	-0.1455
	D2		V1	0.2444	0.1859	0.0683	0.1588	0.2116
		S2	V2	0.1646	0.3073	0.5821	-0.0369	0.223
			V3	0.295	0.2187	0.2484	0.1222	0.1902
			V1	0.1331	0.1263	0.1269	0.0713	0.0102
		S1	V2	-0.0305	0.1917	0.0764	0.1355	0.0437
			V3	0.0486	0.0816	0.1257	0.121	0.0927
	D1		V1	0.0782	0.1187	0.0293	0.1044	0.1255
		S2	V2	0.2033	0.0890	0.1188	0.1245	0.1197
			V3	0.2657	0.1096	0.1955	0.0226	0.0464
T3			V1	0.2478	0.1388	0.1842	0.2192	-0.0016
		S1	V2	0.2357	0.1996	0.0278	0.0998	0.2341
			V3	0.2015	0.0596	0.1123	0.3039	0.1188
	D2		V1	0.0982	0.1544	0.1026	0.0193	0.2005
		S2	V2	0.2976	0.2196	0.2055	0.1728	0.0432
			V3	0.1655	0.2018	0.14	0.1126	0.1361

TABLE III (con't): LATERAL REACTION (kN/m) - BLOCK 2

T	D	S	V	R1	R2	R3	R4	R5
			V1	0.0238	0.0247	0.0691	0.0547	0.0358
		S1	V2	0.1031	0.2206	-0.0211	-0.0264	0.1494
			V3	-0.0502	0.1577	0.0477	0.0427	-0.0482
	D1		V1	0.1735	0.1455	0.0992	0.1	0.085
		S2	V2	-0.0849	0.0009	0.0914	-0.0451	0.1172
			V3	0.18	0.1037	0.1354	-0.0048	0.0617
T1			V1	-0.0104	0.1213	0.2325	0.2527	0.27
		S1	V2	0.088	0.1057	0.159	0.2083	0.0399
			V3	0.1255	0.2075	0.051	0.0003	0.096
	D2		V1	0.1811	0.1943	0.0205	-0.0707	0.1118
		S2	V2	0.0408	0.0117	0.1384	0.1813	-0.0089
			V3	0.5268	-0.0247	0.0291	0.273	0.0706
			V1	-0.0123	0.4012	0.1052	0.2613	0.0075
		S1	V2	0.1141	0.1661	0.007	0.3196	0.061
			V3	0.0935	0.4696	0.1643	0.0444	0.0553
	D1		V1	0.0345	0.3676	0.1744	0.2457	0.1183
		S2	V2	0.1366	0.1783	0.2557	0.2329	0.1748
			V3	0.1608	0.2099	0.2237	0.3275	0.4399
T2			V1	0.2652	0.1833	0.254	0.2713	0.3636
		S1	V2	0.2154	0.2789	0.1677	0.1949	0.2963
			V3	0.2919	0.3395	0.2376	-0.0494	0.1663
	D2		V1	0.4192	0.0996	0.204	0.0787	0.2074
		S2	V2	0.0903	0.2439	0.0903	0.0774	0.1573
			V3	0.1924	0.1512	0.3474	0.3893	0.186
			V1	0.3044	0.3475	0.4757	0.2923	0.4205
		S1	V2	0.4252	0.497	0.1234	0.4003	0.3571
			V3	0.4271	0.4895	0.3956	0.4124	0.1262
	D1		V1	0.341	0.3796	0.0316	0.1689	0.4066
		S2	V2	0.4714	0.4051	0.2137	0.4766	0.4213
			V3	0.3585	0.0702	0.2853	0.4523	0.211
T3			V1	0.4136	0.1973	0.2661	0.4421	0.3725
		S1	V2	0.4069	0.2709	0.3971	0.2839	0.3785
			V3	0.4974	0.3712	0.5658	0.3044	
	D2		V1	0.4781	0.2445	0.2076	0.2662	0.4071
		S2	V2	0.7056	0.2817	0.5532	0.2975	0.3891
			V3	0.5335	0.4287	0.0616	0.3318	0.5055

TABLE III (con't): LATERAL REACTION (kN/m) - BLOCK 3

T	D	S	V	R1	R2	R3	R4	R5
			V1	0.0078	0.0622	0.1582	0.159	0.1521
		S1	V2	0.1171	0.3113	0.128	0.1904	0.3091
			V3	0.356	0.1022	0.4657	0.2703	0.2132
	D1		V1	0.208	0.0695	0.1947	0.1835	-0.7324
		S2	V2	0.1594	0.0656	0.2026	0.0718	0.1248
			V3	0.3848	0.1148	0.1436	0.2395	0.2467
T1			V1	0.1444	0.217	0.0377	0.2083	0.3416
		S1	V2	0.1776	0.0764	0.1743	0.1775	0.1342
			V3	0.2041	0.0476	0.2335	0.0934	0.206
	D2		V1	0.2119	0.2271	0.132	0.0825	0.2196
		S2	V2	0.1119	0.2052	0.1635	0.2186	0.1242
			V3	0.109	0.2097	0.1786	0.1819	0.3222
			V1	0.1347	0.0852	0.1563	0.0459	0.2149
		S1	V2	0.1207	0.1469	0.0559	0.2083	0.1181
			V3	0.1655	-0.0355	0.2327	0.1704	0.0193
	D1		V1	0.1558	-0.0099	0.1342	0.2004	0.1412
		S2	V2	0.2438	0.1625	0.0507	0.0484	0.0364
			V3	-0.0417	0.2278	0.2492	0.076	0.1419
T2			V1	0.1565	0.1836	0.1208	0.1263	0.0907
		S1	V2	0.0277	0.2447	0.2055	0.0871	0.1088
			V3	0.0875	0.1038	0.1891	0.0726	0.1709
	D2		V1	0.0965	0.0907	0.1173	0.1947	0.1002
		S2	V2	0.287	0.1935	0.1279	0.1504	0.0472
			V3	0.0091	0.1887	0.0807	0.0789	-0.0169
			V1	0.1559	0.0353	-0.0778	0.1003	0.1686
		S1	V2	0.2556	0.2926	0.1441	0.262	0.0928
			V3	0.1703	0.1593	0.3174	0.3295	0.1541
	D1		V1	0.1399	0.0959	0.2038	0.043	0.0782
		S2	V2	0.1054	0.037	0.1406	0.0647	0.104
			V3	0.1783	0.2736	0.0219	-0.2211	0.2851
T3			V1	0.1926	0.226	0.1069	0.1797	0.1271
		S1	V2	0.1045	0.2596	-0.0452	0.2211	-0.0441
			V3	0.1264	0.1977	0.2431	0.0508	0.1883
	D2		V1	0.1797	0.2623	0.0464	0.2025	0.1257
		S2	V2	0.2634	0.1104	0.1747	0.1316	0.1491
			V3	0.1937	0.1498	0.1484	0.049	0.1815

TABLE IV: PITCHING COMPONENT (kN/m) - BLOCK 1

T	D	S	V	R1	R2	R3	R4	R5
			V1	0.4887	0.6723	0.5174	0.4295	0.3433
		S1	V2	0.4753	0.502	0.5101	0.5231	0.4515
			V3	0.8338	0.8019	0.7653	0.6438	0.6871
	D1		V1	0.6037	0.4936	0.5882	0.4518	0.3625
		S2	V2	0.6828	0.6013	0.5936	0.4548	0.5384
			V3	1.129	1.045	0.8016	0.642	0.9835
T1			V1	0.5619	0.6024	0.477	0.4033	0.4286
		S1	V2	0.8496	0.5581	0.5884	0.5342	0.521
			V3	0.9212	0.8494	0.8923	0.8499	0.7606
	D2		V1	0.6712	0.4883	0.5017	0.4357	0.8167
		S2	V2	0.8336	0.6437	0.6307	0.6454	0.586
			V3	0.8035	1.031	0.797	0.7972	0.9305
			V1	1.336	1.216	0.935	1.127	0.7741
		S1	V2	1.117	1.324	1.145	1.036	0.8906
			V3	1.152	1.243	1.066	0.9627	0.6878
	D1		V1	1.480	1.194	1.556	1.376	0.9531
		S2	V2	1.527	1.100	1.133	1.113	1.107
			V3	1.501	1.460	1.587	0.791	1.190
T2			V1	1.352	1.113	1.684	1.090	0.9162
		S1	V2	1.193	1.381	1.154	1.208	0.8904
			V3	1.457	1.333	1.190	1.085	0.9967
	D2		V1	1.487	1.274	1.370	1.210	1.274
		S2	V2	1.266	1.582	1.230	1.116	1.128
			V3	1.683	1.860	1.733	1.436	1.463
			V1	0.9308	0.898	0.4719	0.6283	0.9265
		S1	V2	0.9696	1.564	0.6806	0.9796	0.7057
			V3	0.7918	0.8787	1.505	1.257	0.8041
	D1		V1	0.8348	0.8027	0.6371	0.7544	0.4961
		S2	V2	0.9734	1.115	0.8751	0.8565	1.221
			V3	1.080	1.444	1.065	0.7305	1.020
T3			V1	1.095	0.8533	0.7461	0.6637	0.7169
		S1	V2	1.278	0.8617	0.6592	0.794	0.9196
			V3	1.220	0.8672	0.8591	0.8844	0.8834
	D2		V1	0.9022	0.8011	0.7562	0.8231	0.7129
		S2	V2	1.200	0.93	1.115	0.9421	0.9354
			V3	1.399	1.100	1.157	1.000	0.8483

TABLE IV (con't): PITCHING COMPONENT (kN/m) - BLOCK 2

T	D	S	V	R1	R2	R3	R4	R5
			V1	0.5213	0.861	0.4783	0.4744	0.7503
		S1	V2	0.9924	0.701	0.6433	0.5443	0.6069
			V3	0.8769	1.123	0.9003	0.5824	0.3035
	D1		V1	1.266	0.4292	0.7764	0.6154	0.5119
		S2	V2	0.6505	0.6267	0.5088	0.3867	0.7053
			V3	1.045	0.259	0.5414	0.553	1.024
T1			V1	0.8397	0.8227	0.8745	0.7894	1.003
		S1	V2	0.8172	1.080	0.9684	0.9986	0.681
			V3	1.316	0.8766	0.29	0.5733	0.7347
	D2		V1	0.9517	0.8284	0.891	0.6587	0.677
		S2	V2	1.080	0.7833	0.6679	0.8809	0.4416
			V3	1.109	0.5462	0.523	0.9601	0.6594
			V1	1.553	1.198	1.154	1.350	0.8146
		S1	V2	1.725	1.211	0.6965	0.6258	0.9958
			V3	1.631	1.301	0.8281	0.6482	0.3948
	D1		V1	1.415	1.041	0.8914	0.6679	0.5919
		S2	V2	0.9026	1.256	1.161	0.9592	0.7883
			V3	1.174	1.459	0.9929	1.163	1.521
T2			V1	0.9988	1.373	1.467	0.9991	1.461
		S1	V2	1.135	1.292	0.9244	0.7144	1.140
			V3	0.976	1.365	1.261	1.500	0.9069
	D2		V1	1.280	0.9264	0.9137	1.064	1.006
		S2	V2	1.730	0.6229	1.325	0.8759	0.7528
			V3	1.745	0.9456	1.373	1.049	0.9982
			V1	1.972	1.767	3.347	2.463	1.083
		S1	V2	2.773	2.723	0.6253	2.232	0.8339
			V3	3.244	3.004	2.407	2.679	0.708
	D1		V1	2.663	1.358	0.7876	0.9482	1.584
		S2	V2	2.244	2.620	1.030	1.509	2.434
			V3	2.385	1.458	0.857	2.058	1.083
T3			V1	2.451	1.637	1.662	1.576	2.431
		S1	V2	2.614	1.741	2.019	1.898	2.442
			V3	3.000	2.754	1.768	1.798	2.860
	D2		V1	2.034	0.7089	1.471	1.583	1.524
		S2	V2	2.851	0.858	2.000	1.346	1.529
			V3	2.157	2.067	0.740	1.409	1.871

TABLE IV (con't): PITCHING COMPONENT (kN/m) - BLOCK 3

T	D	S	V	R1	R2	R3	R4	R5
			V1	2.213	1.566	1.852	1.565	1.612
		S1	V2	2.381	2.291	1.495	2.917	1.592
			V3	1.803	1.757	2.117	1.907	2.382
	D1		V1	1.184	1.196	1.465	1.282	1.113
		S2	V2	1.970	1.954	1.831	1.211	2.043
			V3	2.630	1.859	1.605	2.169	2.266
T1			V1	1.396	1.343	1.229	1.374	2.424
		S1	V2	1.582	1.453	1.338	1.600	2.018
			V3	2.014	1.867	1.779	1.684	2.368
	D2		V1	1.772	1.388	1.199	1.291	1.329
		S2	V2	1.916	1.337	1.289	1.28	0.932
			V3	1.820	1.621	1.775	1.363	1.429
			V1	1.408	1.445	1.417	1.541	1.585
		S1	V2	1.528	1.823	0.6017	0.9169	1.584
			V3	2.113	1.384	2.037	0.89	1.895
	D1		V1	1.229	1.014	1.143	1.382	1.321
		S2	V2	1.305	1.616	1.421	1.203	0.5498
			V3	1.287	1.531	2.373	1.632	1.590
T2			V1	1.587	1.67	1.160	1.288	1.327
		S1	V2	1.519	1.566	1.706	1.430	2.063
			V3	1.906	1.589	1.432	1.298	1.178
	D2		V1	1.944	1.444	1.271	0.960	1.223
		S2	V2	1.954	1.673	1.031	1.350	1.800
			V3	2.216	2.156	2.647	1.580	1.396
			V1	1.396	1.023	0.8022	0.8441	1.917
		S1	V2	1.574	1.566	0.7686	0.9553	0.6699
			V3	2.249	0.7861	1.284	2.080	1.167
	D1		V1	1.248	1.408	1.107	0.8115	1.022
		S2	V2	1.460	1.405	0.7686	0.6822	0.8826
			V3	1.446	1.320	1.182	0.4756	0.9009
T3			V1	1.564	1.352	1.100	1.651	1.026
		S1	V2	1.390	1.974	1.4	1.648	0.7035
			V3	2.069	1.819	1.294	1.466	1.666
	D2		V1	1.969	1.169	0.7509	0.9352	1.095
		S2	V2	1.872	1.030	1.094	0.9096	0.8224
			V3	1.549	1.962	1.363	1.031	1.523

TABLE V: ROLLING COMPONENT (kN/m) - BLOCK 1

T	D	S	V	R1	R2	R3	R4	R5
			V1	0.2665	-0.0241	0.0117	0.0494	-0.0025
		S1	V2	0.025	0.055	0.111	0.0207	0.0454
			V3	0.0027	0.0218	0.061	-0.0001	0.019
	D1		V1	0.0048	0.1104	0.0029	0.0164	0.0134
		S2	V2	-0.0166	0.0307	0.0075	-0.0163	0.0235
			V3	0.1216	0.0012	-0.0245	0.0254	0.0225
T1			V1	0.0112	0.0225	0.0125	0.0021	-0.002
		S1	V2	0.0573	-0.027	0.0526	0.0043	0.0248
			V3	0.0565	0.0411	0.0597	0.0601	-0.0476
	D2		V1	0.0396	0.0231	0.0117	0.029	0.0123
		S2	V2	-0.027	0.0187	-0.0393	-0.0209	0.0245
			V3	0.0662	0.0113	0.0035	0.0403	-0.0308
			V1	-0.021	-0.0841	-0.0014	-0.1366	0.0019
		S1	V2	-0.0812	0.163	-0.0161	-0.0795	-0.0049
			V3	-0.0519	-0.1138	0.0202	-0.0276	-0.0885
	D1		V1	-0.0193	-0.0474	0.2878	-0.0106	-0.016
		S2	V2	0.0927	-0.0832	-0.0069	-0.0642	-0.035
			V3	-0.0993	0.0072	-0.0856	-0.027	-0.0707
T2			V1	-0.0572	-0.0155	0.0498	-0.0985	0.0396
		S1	V2	-0.01	0.0043	0.0401	0. 551	0.0267
			V3	0.0338	0.0416	-0.0089	-0.0542	0.0417
	D2		V1	0.0075	-0.0829	-0.0548	-0.0296	-0.013
		S2	V2	-0.0866	-0.1423	-0.164	0.0349	-0.0033
			V3	-0.09	0.0092	-0.0079	0.0106	0.0334
			V1	-0.0628	-0.0395	-0.0501	-0.0521	-0.0159
		S1	V2	-0.0011	-0.0494	-0.0358	0.0139	0.0019
			V3	-0.05	-0.0984	0.0556	-0.0578	-0.0971
	D1		V1	0.0406	-0.0055	-0.0139	-0.0179	-0.007
		S2	V2	-0.0425	-0.0274	-0.012	0.0418	-0.0081
			V3	-0.1209	0.0178	-0.0849	-0.0174	-0.0413
T3			V1	-0.0995	-0.0369	-0.0681	-0.0636	0.0022
		S1	V2	-0.0829	-0.0728	-0.0425	-0.072	-0.096
			V3	-0.0881	-0.1267	-0.1229	-0.2589	-0.046
	D2		V1	-0.05	-0.0667	-0.0469	-0.0105	-0.0679
		S2	V2	-0.1065	-0.0303	-0.1084	-0.0657	-0.046
			V3	-0.0629	-0.1091	-0.1028	-0.103	-0.0493

TABLE V (con't): ROLLING COMPONENT (kN/m) - BLOCK 2

T	D	S	V	R1	R2	R3	R4	R5
			V1	0.0203	-0.0324	-0.0019	-0.0349	-0.0039
		S1	V2	0.0229	-0.053	-0.0138	0.0124	-0.031
			V3	0.0515	-0.0826	0.1364	0.133	-0.0462
	D1		V1	-0.0167	-0.0638	-0.0417	-0.0019	0.0646
		S2	V2	0.3111	0.0322	-0.0096	0.0037	-0.0186
			V3	0.0579	-0.0221	-0.0089	-0.0038	0.0144
T1			V1	-0.012	-0.0325	-0.1286	-0.0495	-0.0643
		S1	V2	-0.0297	-0.1246	-0.0379	-0.0285	-0.0091
			V3	-0.0274	0.033	0	0.0983	-0.0644
	D2		V1	-0.0625	-0.0292	-0.0706	-0.0464	-0.0302
		S2	V2	-0.037	-0.06	-0.0265	-0.0858	-0.0196
			V3	0.2653	-0.0178	-0.0439	-0.0286	-0.0988
			V1	0.0277	-0.2908	-0.1196	-0.0222	0.0083
		S1	V2	-0.0318	-0.0979	-0.0453	-0.0472	-0.0808
			V3	-0.0614	-0.0948	-0.0353	-0.0372	0.024
	D1		V1	-0.0052	-0.0653	-0.1536	-0.0566	-0.0154
		S2	V2	-0.026	-0.1754	-0.1091	-0.0888	-0.0651
			V3	0.0853	0.0452	-0.0983	-0.1963	-0.3015
T2			V1	0.0094	-0.0284	-0.0516	-0.2055	-0.1623
		S1	V2	-0.1432	-0.0446	-0.0658	0.0149	-0.074
			V3	-0.0758	-0.0895	0.0023	-0.0202	-0.1263
	D2		V1	-0.2041	-0.1191	-0.159	-0.07	-0.0267
		S2	V2	-0.0604	0.0753	0.0628	-0.076	-0.0072
			V3	-0.1201	0.1018	-0.2765	-0.1736	-0.093
			V1	-0.0487	-0.216	-0.0597	0.1466	-0.4783
		S1	V2	-0.453	-0.341	-0.1347	-0.4907	-0.1663
			V3	-0.399	-0.0627	-0.0995	0.0432	-0.132
	D1		V1	0.0628	-0.2012	-0.0642	-0.1464	-0.2798
		S2	V2	-0.2322	-0.478	-0.1007	-0.3506	-0.0386
			V3	-0.0257	-0.0574	-0.1106	-0.176	-0.0887
T3			V1	-0.1141	-0.4723	0.0202	-0.216	-0.5442
		S1	V2	-0.1834	-0.3247	-0.2787	-0.6325	-0.0759
			V3	0.0389	-0.0742	-0.2316	-0.3924	-0.1124
	D2		V1	-0.2679	-0.1948	-0.2324	-0.1714	-0.2424
		S2	V2	-0.2609	-0.256	-0.251	-0.1017	-0.4827
			V3	-0.3269	-0.2944	-0.1995	-0.2063	-0.7116

TABLE V (con't): ROLLING COMPONENT (kN/m) - BLOCK 3

T	D	S	V	R1	R2	R3	R4	R5
			V1	0.1955	0.0776	0.1001	0.0228	0.0991
		S1	V2	0.2681	0.0027	0.0075	0.3336	-0.0411
			V3	0.2378	0.1487	0.0085	-0.0673	0.0357
	D1		V1	-0.0192	0.0416	0.0185	0.0647	-0.9003
		S2	V2	0.1364	0.1476	-0.1505	0.0302	0.1287
			V3	0.0655	0.0903	0.0245	0.0347	0.0387
T1			V1	0.0208	-0.0181	0.0673	-0.0014	0.0841
		S1	V2	0.0626	0.089	0.0425	0.0732	0.161
			V3	0.0761	0.0276	0.1253	-0.0331	0.2044
	D2		V1	0.0233	-0.0211	0.034	0.0341	0.1596
		S2	V2	0.1256	0.0526	0.0525	-0.0465	0.0213
			V3	0.0633	0.0701	0.0184	0.0774	-0.112
			V1	0.0282	0.0461	-0.0115	0.1157	0.0129
		S1	V2	0.0534	0.1676	-0.0014	-0.0351	0.1252
			V3	0.0776	0.2949	0.0829	-0.1232	0.2484
	D1		V1	0.0815	0.0567	0.0115	0.0655	0.0205
		S2	V2	0.0434	0.0948	0.106	-0.0488	0.0362
			V3	0.1265	0.0177	0.1009	0.1181	-0.0657
T2			V1	0.089	0.0447	0.0341	0.0304	0.1153
		S1	V2	0.0465	-0.1467	-0.0654	0.0609	0.2467
			V3	0.2073	0.0557	0.0402	0.0688	0.0015
	D2		V1	0.0956	0.0628	0.0145	-0.0184	0.0276
		S2	V2	0.0447	0.0417	0.0313	0.0397	0.0067
			V3	0.1017	0.0709	0.1657	0.1879	0.0655
			V1	-0.0618	0.0324	0.023	-0.0077	0.072
		S1	V2	0.0174	-0.0941	-0.0309	-0.1673	-0.0466
			V3	0.0229	-0.0257	-0.2035	-0.0033	-0.0701
	D1		V1	-0.0257	-0.0031	-0.1272	-0.0705	0.0331
		S2	V2	0.1054	0.1747	0.0162	0.0928	-0.0072
			V3	0.0164	-0.145	0.0482	0.0185	-0.0545
T3			V1	-0.0184	-0.029	-0.0219	-0.0603	0.0418
		S1	V2	-0.0246	0.1145	0.0002	-0.0072	0.303
			V3	0.2664	0.0773	-0.08	0.052	-0.0301
	D2		V1	0.0548	-0.051	0.007	-0.0594	0.0369
		S2	V2	0.0652	0.0418	-0.055	0.0052	0.0012
			V3	0.0131	-0.0304	-0.0347	0.0065	-0.0203

TABLE VI: YAWING COMPONENT (kN/m) - BLOCK 1

T	D	S	V	R1	R2	R3	R4	R5
			V1	-0.024	0.0263	-0.0188	-0.0238	0.0051
		S1	V2	-0.0251	-0.0492	-0.0406	0.0444	-0.0317
			V3	0.02	-0.0055	-0.0335	0.0317	-0.0194
	D1		V1	0.0315	0.0418	0.0207	-0.0228	-0.0083
		S2	V2	0.0406	-0.0141	-0.0077	0.0297	-0.014
			V3	-0.059	0.036	0.0365	-0.0142	0.0005
T1			V1	-0.0119	0.024	-0.0124	-0.0015	0.0089
		S1	V2	-0.0352	0.0144	-0.0323	0.0134	-0.0045
			V3	-0.0288	-0.0191	-0.0173	-0.0123	0.0432
	D2		V1	-0.0258	-0.003	-0.0041	-0.0309	-0.0029
		S2	V2	0.024	-0.0139	0.0283	0.0046	0.0064
			V3	-0.0362	0.0093	0.0083	-0.0178	0.0443
			V1	0.0278	0.0672	0.0372	0.0747	0.0137
		S1	V2	0.0836	-0.0908	0.0528	0.0565	0.0139
			V3	0.0667	0.113	0.0244	0.0305	0.066
	D1		V1	0.0432	0.0183	-0.107	0.0192	0.0305
		S2	V2	-0.0325	0.0782	0.0385	0.0805	0.0566
			V3	0.0983	0.0189	0.0899	0.0538	0.0924
T2			V1	0.0747	0.0475	0.0088	0.0887	-0.0194
		S1	V2	0.0217	0.0178	0.0079	-0.0261	-0.0072
			V3	0.0462	-0.0253	0.0278	0.0743	-0.0125
	D2		V1	0.0371	0.0655	0.0851	0.0458	0.0259
		S2	V2	0.0875	0.1228	0.1399	-0.0074	0.0437
			V3	0.1027	0.0189	0.0659	0.0312	0.0104
			V1	0.0505	0.0444	0.0313	0.0433	0.0277
		S1	V2	0.0162	0.067	0.0385	0.0149	0.0282
			V3	0.0461	0.0651	-0.0255	0.0682	0.0784
	D1		V1	0.0449	0.0357	0.0174	0.0296	0.0112
		S2	V2	0.0595	0.0423	0.0309	0.033	0.0207
			V3	0.0908	0.0116	0.0718	0.023	0.0548
T3			V1	0.086	0.0451	0.0523	0.0499	0.0099
		S1	V2	0.0761	0.0614	0.0348	0.0708	0.082
			V3	0.0745	0.0893	0.0871	0.1061	0.0496
	D2		V1	0.0504	0.0638	0.0453	0.0256	0.0531
		S2	V2	0.0907	0.0429	0.0861	0.057	0.0476
			V3	0.102	0.0905	0.0901	0.0846	0.0428

TABLE VI (con't): YAWING COMPONENT (kN/m) - BLOCK 2

T	D	S	V	R1	R2	R3	R4	R5
			V1	0.0116	0.0278	-0.0013	0.0321	0.0175
		S1	V2	-0.011	0.0584	0.0176	-0.0047	0.0336
			V3	0.015	0.076	-0.0395	-0.015	0.0398
	D1		V1	0.0135	0.0514	0.0446	0.0103	0.0098
		S2	V2	-0.1002	0.0103	0.0011	-0.0039	0.0344
			V3	0.0027	0.0237	0.0113	-0.0173	-0.0036
T1			V1	0.0232	0.0341	0.0899	0.0522	0.0611
		S1	V2	0.0387	0.0797	0.0448	0.0315	-0.0004
			V3	0.0505	0.0205	0.004	-0.0192	0.0491
	D2		V1	0.049	0.0363	0.0547	0.0233	0.0406
		S2	V2	0.0197	0.0477	0.0307	0.0581	0.0155
			V3	0.3291	0.0281	0.038	0.0567	0.0673
			V1	0.0042	0.2401	0.1096	0.0836	0.0161
		S1	V2	0.0733	0.0843	0.0465	0.0629	0.0885
			V3	0.0342	0.1195	0.0554	0.0507	0.0079
	D1		V1	0.0521	0.0972	0.1038	0.053	0.0298
		S2	V2	0.0497	0.1422	0.118	0.114	0.0704
			V3	0.0632	0.0515	0.0827	0.1769	0.1997
T2			V1	0.0551	0.1009	0.1254	0.1409	0.1663
		S1	V2	0.1017	0.0838	0.0876	0.0184	0.0931
			V3	0.1443	0.1063	0.0663	0.0525	0.1012
	D2		V1	0.1682	0.0627	0.1093	0.1081	0.0419
		S2	V2	0.0757	0.0211	0.0074	0.0694	0.0397
			V3	0.141	0.0577	0.2124	0.1253	0.0859
			V1	0.074	0.1722	0.0696	-0.0056	0.147
		S1	V2	0.0707	0.2566	-0.0285	0.1387	0.1219
			V3	0.0434	0.0934	0.1084	0.0142	0.0294
	D1		V1	0.0036	0.1462	-0.0081	0.1209	0.1805
		S2	V2	0.1878	0.1382	0.0885	0.2305	0.1156
			V3	0.0806	0.0799	0.0953	0.1366	0.0327
T3			V1	0.1214	0.1707	0.0695	0.2039	0.1157
		S1	V2	0.193	0.0429	0.2211	0.1766	0.1305
			V3	0.0571	0.1257	0.2117	0.2772	-0.0096
	D2		V1	0.2452	0.0087	0.1811	0.1506	0.1953
		S2	V2	0.1825	0.0695	0.187	0.1032	0.1427
			V3	0.2834	0.1908	0.1188	0.1701	0.2035

TABLE VI (con't): YAWING COMPONENT (kN/m) - BLOCK 3

T	D	S	V	R1	R2	R3	R4	R5
			V1	-0.0906	-0.0215	-0.0261	0.0154	-0.0146
		S1	V2	-0.1031	0.0437	0.0387	-0.0926	0.052
			V3	-0.0351	-0.0546	0.0237	0.0752	0.0442
	D1		V1	0.0444	0.0104	0.0241	-0.0283	-0.8816
		S2	V2	-0.0391	-0.0509	0.1412	0.02	-0.008
			V3	0.023	-0.0027	0.0694	0.0353	0.0364
T1			V1	0.0214	0.035	-0.0014	0.0243	0.0133
		S1	V2	0.004	-0.0046	0.0125	0.0033	-0.0173
			V3	-0.0035	0.0309	-0.0255	0.0709	0.093
	D2		V1	0.0284	0.0376	0.0193	0.0089	0.0271
		S2	V2	-0.0279	0.0051	-0.002	0.052	0.0144
			V3	-0.0022	0.004	0.0279	-0.0073	0.093
			V1	-0.0977	-0.1042	-0.0741	-0.1714	-0.0909
		S1	V2	-0.1202	-0.2116	-0.0245	-0.0241	-0.163
			V3	-0.1803	-0.2826	-0.1721	0.0267	-0.2339
	D1		V1	-0.1207	-0.0861	-0.0758	-0.1313	-0.119
		S2	V2	-0.0893	-0.1575	-0.1623	-0.0552	-0.0555
			V3	-0.2011	-0.1175	-0.191	-0.1573	-0.0691
T2			V1	-0.1386	-0.1209	-0.0897	-0.0957	-0.1461
		S1	V2	-0.117	0.0031	-0.0741	-0.1234	-0.2754
			V3	-0.2594	-0.1098	-0.1085	-0.1321	-0.0627
	D2		V1	-0.1879	-0.1402	-0.0788	0.0418	-0.1019
		S2	V2	-0.1277	-0.1759	-0.0624	-0.1164	-0.044
			V3	-0.1937	-0.1872	-0.2516	0.1966	-0.1345
			V1	-0.0604	-0.1002	-0.0936	-0.0655	-0.1593
		S1	V2	-0.1138	-0.0461	0.0277	0.0217	-0.0128
			V3	0.166	-0.0208	0.0506	-0.1136	-0.0297
	D1		V1	-0.0637	-0.0887	-0.0019	-0.014	-0.0786
		S2	V2	-0.1528	-0.2082	-0.0565	-0.0855	-0.0498
			V3	-0.0903	0.0051	-0.104	-0.0287	-0.0266
T3			V1	-0.1176	-0.0839	-0.0656	-0.0992	-0.0889
		S1	V2	-0.0736	-0.1889	-0.1046	-0.1068	-0.0361
			V3	-0.2326	0.1451	0.0394	-0.1303	-0.0918
	D2		V1	-0.179	-0.0552	-0.0544	-0.0375	-0.0791
		S2	V2	-0.1532	-0.0901	-0.0336	-0.0679	-0.048
			V3	-0.1509	-0.1205	-0.0819	-0.0676	-0.0906

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